VOLUME 51 NUMBER 4 . . . ONE YEAR THREE FIFTY

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GENERAL ELECTRIC

REVIEW

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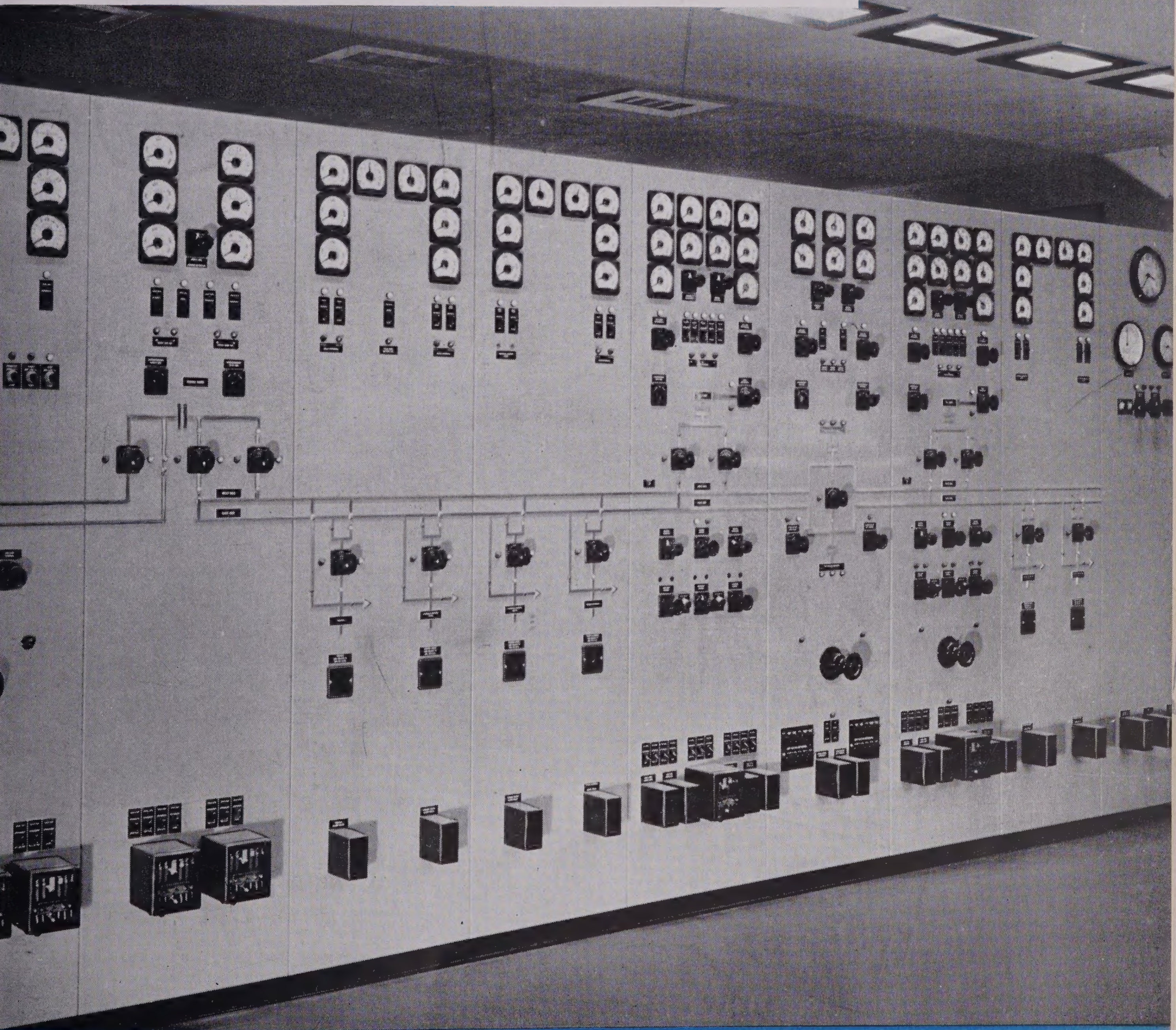

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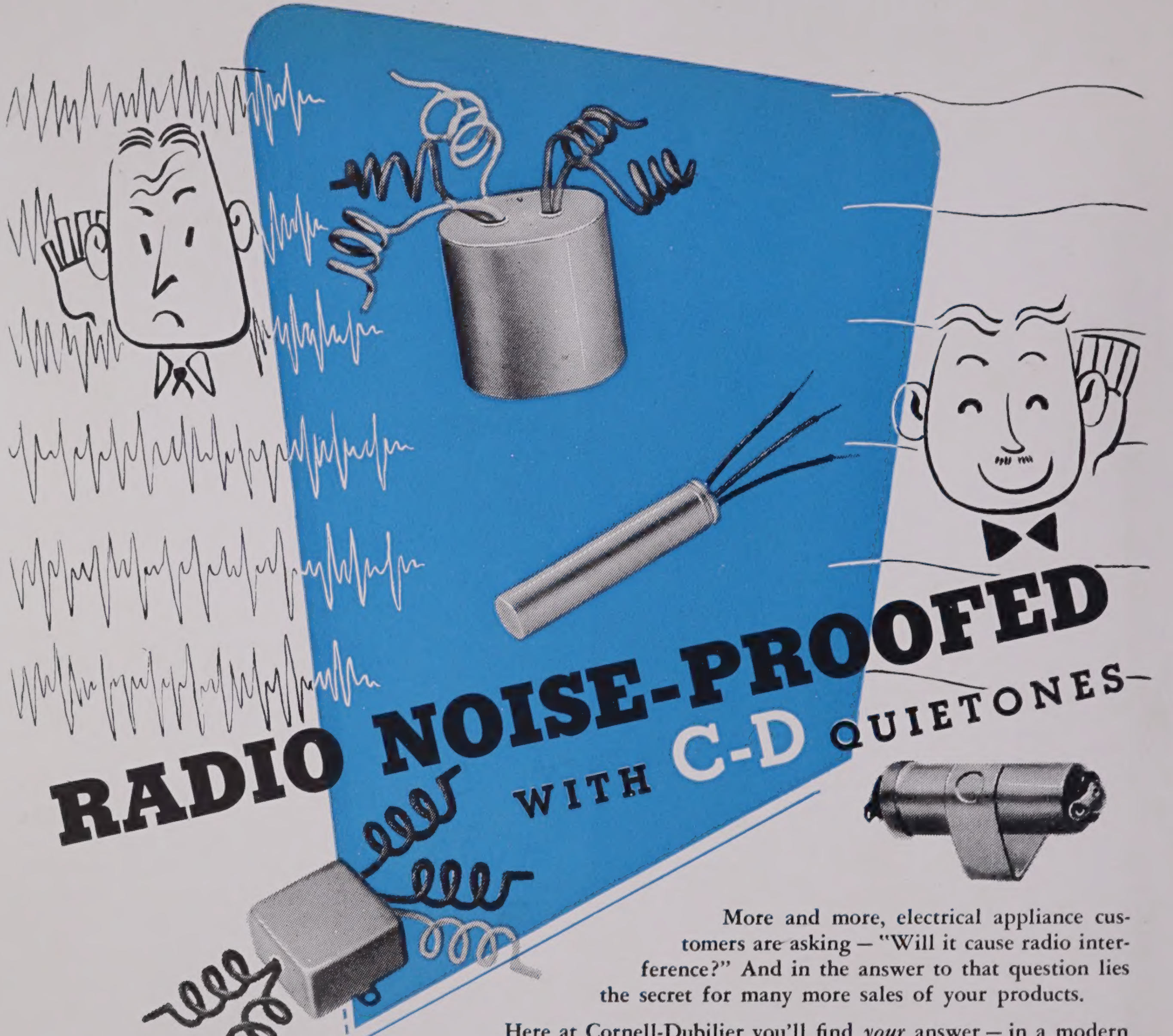

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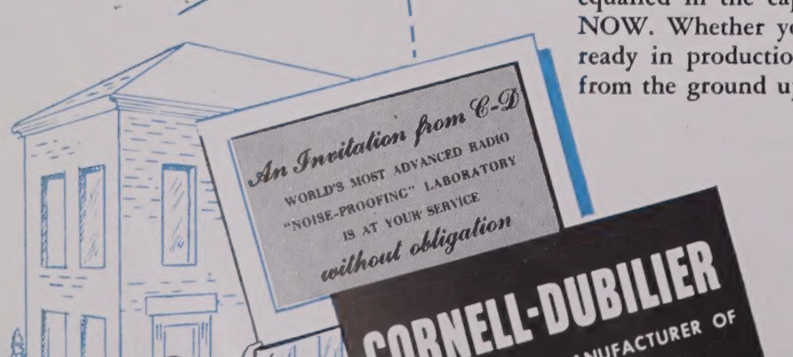
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GENERAL ELECTRIC Review

APRIL, 1948
Vol. 51, No. 4

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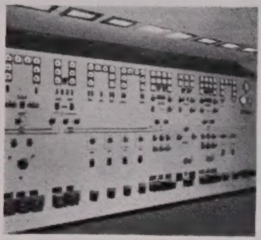

THE COVER

A main control board upon the upper panels of which are mounted sixty-seven long-scale wide-angle instruments used in the operation of a modern steam-electric power plant. Longer scales in smaller space is however but one of the features resulting from recent improvements in the basic design of switchboard instruments. The development and characteristics of these new instruments are described in the article on page 14.

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CIRCULATION DEPARTMENT: General Electric Review, Schenectady 5, New York. Great Britain: General Electric Review, Crown House, Aldwych, London, W. C. 2, England.

SUBSCRIPTION RATES: *Payable in advance.* United States and Possessions and countries in Pan-American Union, one year $3.50, two years $5.50. Canada, one year $3.75, two years $5.75. Other foreign countries, $4.00 a year, $6.00 two years. Public and college libraries, professors, and enrolled students deduct $1.00 from annual rates. SINGLE COPY 35¢

CHANGE OF ADDRESS: Give old and new addresses. Notices received before the fifteenth of the month will be effective with the next issue.

ADVERTISING DEPARTMENT: General Electric Review, Schenectady 5, New York.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under Act of March 3, 1879. Published monthly by General Electric Company, 1 River Road, Schenectady 5, N. Y. Printed in U. S. A. Copyright 1948 by General Electric Company.

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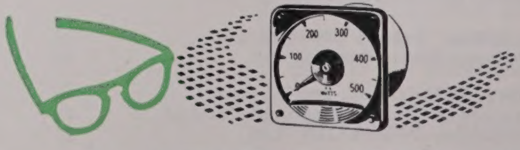

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LOOKING TOWARD MAIN STREET

Where industry's awareness of its new role in American life must stand the test—and the present test concerns a program to beat inflation

CEWilson

By CHARLES E. WILSON
President, General Electric Company

MANY managers in industry are today spending more and more of their time looking out their office window toward Main Street and what is going on there.

No longer can managers of business concentrate their whole attention upon manufacturing and selling, as they once did. Industry has matured in America, and the economic and sociological implications of this maturity are all about us. Industry is not only the manager; it is the employee, the stockholder, and even the customer. The day has passed when an employee can limit his concern to the time clock and the pay envelope, and when a stockholder can confine his interest to his dividend checks. In our economy even a buyer of merchandise and services should bring to his role a sort of moral pattern, in the sense of encouraging through his custom those enterprises which also offer responsibility and integrity. Managers must therefore act as trustees for employees, stockholders, and public. The morals and motives of business, its habits and character as a citizen in the community in which it lives—these things are today of prime importance.

One should not have to look beyond his own community to find a growing awareness of this sense of trusteeship on the part of business men. There are in the country today many voluntary efforts to plant this standard, but progress will be slow for which reason patience will be necessary. First of all, there is the movement that begins at the bottom, with the individual, with the small business, in a specific community. Here are the men who can supply the real strength, even though much of their time must be preoccupied with their own problems of making a living. Second, there is the machinery by which this social evolution is being achieved—for example, such motivating bodies as the United States Chamber of Commerce; The Advertising Council; The Joint Committee of the two great advertising associations, one made up of the agencies and the other of advertisers; and the various similar groups drawn from business, labor, and the professions. These associations are now voluntarily trying to apply their talents to the tremendous job of uniting, strengthening, and advancing the people of the United States along the road to their manifest destiny.

So far I have dealt with the sense of trusteeship in only a very general way. Now let us turn to what is perhaps the most immediate need for it—the combatting of inflation. While there has been a great deal of argument on this subject, it is generally recognized that there are three solutions to inflation: one of them is doing nothing; the others call for action.

It is the first solution which should keep us awake nights, because it has only one inevitable end, and that is depression. Most of us have been through this wringer before and can pretty well recall what happened. The scars of the last depression still color the economic and political thinking of the majority of American adults. This time, a depression would be even more serious, and it would probably destroy the American economic and political system as we have known it. This is because of our new position of world leadership, inherited from the ruins of World War II, and of the extreme dependence of the rest of the world, particularly the western world, upon the continuance of our economic leadership.

With each advance in prices of such items as food, clothing, and shelter, pressure increases upon all business and industry to meet those higher living costs with higher wages. Higher labor costs are immediately and necessarily reflected in higher prices for manufactured goods—and with each advance in prices we narrow our market and proceed to price ourselves out of it. This is because not everyone shares in the wage increase, of course. The vast number of people who live on fixed incomes from investments, trusts, pensions, annuities, and so on, just cannot keep up, because their fixed income in inflation dollars buys less and less. This shadow is followed by a blacker one—RELIEF—because inflation is a process that eventually begins to take in presently employed wage-earners, as demand for goods falls off and shops close. We can go down even faster than we went up, and it is harder to stop. So much for the hard and cruel depression—or bust—solution to inflation. To say that we don't want it is an understatement.

The first of the remaining two solutions is government control of prices and wages, with rationing, black markets, and the rest. We have had some rather horrible examples of this planned scarcity. We have just finished fighting a war to make sure that we would not have a state-controlled economy. Under such a development the American enterprise system could not

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This article is based on an address given by Mr. Wilson at the recent annual conference of the U. S. Conference of Mayors.—Ed.

This article is so paged that, without mutilating other articles, it can be conveniently removed for separate filing by tearing out pages 11 to 12.—Ed.

continue to exist—in fact it is this American system, and no other, which has made us the deciding factor in two world wars and which has given us our present economic position in the world.

There remains the third solution—the most difficult of all because it is the most satisfactory in its results; the most difficult of all because it must proceed largely from voluntary action by individual citizens and individual companies acting intelligently and unselfishly. The real facts about our inflation are gradually becoming more widely known and understood. National holdings of bonds and cash were swelled during the war by new money, created to pay the people who produced the goods of war. What they produced was then shot away—they were unable to spend their money on it as ordinarily happens to what we produce. Even now we have a new twist to this inflationary process represented by our tremendous agricultural and industrial production for export—this will take away once more from the things that we are able to spend our money for at home. Because we have too much money and too few goods, prices rise, and the dollar we earn is worth less and less. That brings us almost down to date.

The only thing that industry can do, in the face of such a situation, is to *produce more out of the existing wage dollar*. Obviously, to increase wages is only to add to available money. It adds nothing to the supplies of food, clothing, or manufactured goods—and the dog simply chases its tail. What makes this a tough situation will become clearly evident by my now switching from the general to the following simple example—the experience of the General Electric Company, about which I can speak with more authority as to the facts.

In two years we have granted two, flat, wage increases. Last year we added some 50 million dollars to our payroll by such a move. In neither case did we deem this wise, but in neither case did we have a choice. Under similar circumstances we would have no choice again, because we have a policy of paying the going wage, or better, for any community in which we do business, for comparable kinds of work. As long as living costs rise, community wage levels will rise, and added labor costs will result in necessarily increased prices of the things we make. Too many people are fooled into a false sense of well being by the extra money—the feeling of being richer—and they get lax in their work and careless in their spending of income and savings.

This is where the first misleading element creeps in. Corporate profits, including our own, have looked very large in terms of dollars, but this is because we have tremendously increased our volume. We were able to do that because we have expanded our facilities and added to our employees even beyond wartime levels. We are doing a lot more business than we ever did before—but the net profit which we are getting back out of the sales dollar is less than half what it was before the war.

It is ridiculous to draw any conclusions, as so many have done, from the profits shown before taxes. It is just as ridiculous, as so many more have done, to draw conclusions from the ratio of profit on investment. The cold fact remains that when the product is made and sold, and the money collected, and our expenses of doing business paid, we have left less than half as much from each dollar of sales as we had prewar. Frankly, we do not consider this a safe operating margin. Yet on January 1 of this year, General Electric did something that tended to reduce even that too-small margin. We reduced prices. That looks like bad management, so I want to outline what our thinking was.

Some have called it a gesture, and I guess it was, but even gestures can be costly. We calculated that this one would result in savings of 50 million dollars to consumers. We do not think for a moment that our single action will directly reduce the cost of living for any of our employees. We do not think for a moment that by itself it will reverse the inflationary trend. It might be said that what we hoped to do by this act was to buy our way into a spot where we could legally and morally urge other companies to try the same thing, where we could honorably and logically urge our employees to start an anti-inflation campaign of their own by buying less expensive foods, making clothes last a little longer, adding to their savings instead of taking away from them to pay current expenses. This is exactly what we are doing. What will be the result of this honest effort—within our limited means to better the lot of all Americans—is in the lap of the gods at the moment.

To combat inflation we immediately set out to cut our manufacturing costs by five per cent. We set out to persuade the people who supply us with materials and components to reduce their prices to us. We set out to persuade people who buy motors and other component parts from us, on which we had reduced prices, to reduce their prices in turn. We have in progress a very elaborate campaign with our employees, in most of the cities where we have a plant, which starts with management and supervisors and goes on down, educating, urging, showing. We suggest that they do everything in their power to help the program to catch on in their communities. We are trying to work with merchants, banks, and others. We know that in the end, when the chips are down, it is the individual, exercising intelligence and self-restraint because he understands what he is doing, who will determine the success or failure of this program, and who will prove in his own fashion whether this system of ours has the power to cure inflation in its own orderly way.

No diagram is needed to show what this can mean in a community; neither is a diagram needed to show what each of us, as citizens of that community, should be doing about it. This is something that has to begin at home. Always remember that important key word—*Voluntary*. There is no voluntary action when everybody sits and waits for something to happen—for somebody else to do something first. Only by resolute and thorough examination of one's own resources and opportunities, followed by determination to set so inspiring an example that others will follow, can inflation be checked.

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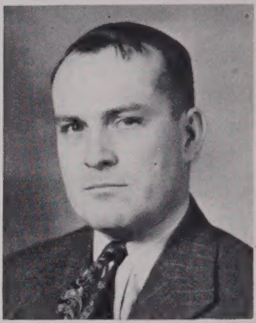
NEW LONG-SCALE INSTRUMENTS

R. M. Rowell

Recent improvements in materials and techniques have yielded new instruments for modern switchboards

By R. M. ROWELL and N. P. MILLAR
Instrument Engineering Division, West Lynn Works
General Electric Company

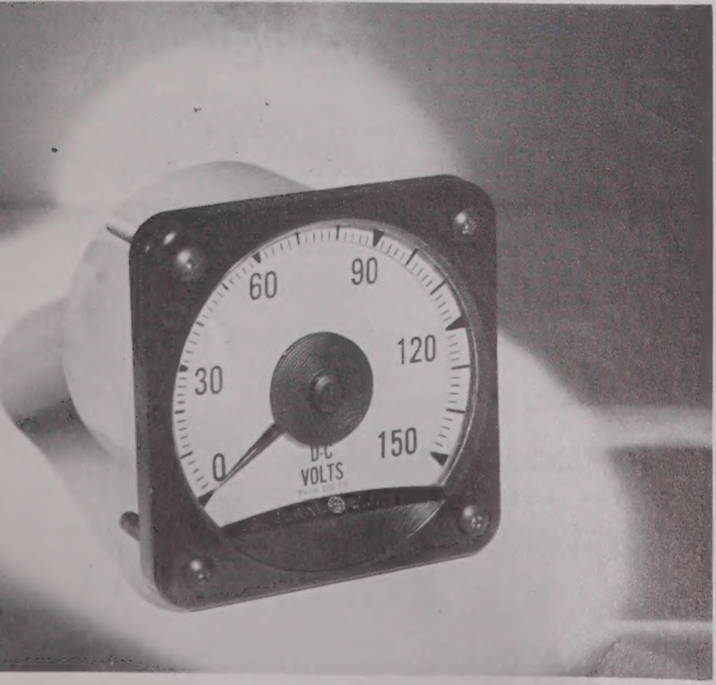


N. P. Millar

LONG-SCALE wide-angle switchboard instruments combine an increase in scale length with smaller panel space requirements.(1) Long-scale instruments were not new, but only shortly before the war had new materials and techniques become sufficient to make a comprehensive variety of such instruments feasible for accurate electrical measurement under the widely varying conditions encountered in practice.

The long-scale 4¼-in. square instruments at once found wide acceptance. They can be mounted with remarkable economy of space on switchboard panels. For example, on a panel two feet square it is possible to mount 25 of the long-scale instruments, compared to nine of the conventional six-inch rectangular flush type. Moreover, each of the compact new instruments has a scale length 36 per cent greater than that of the larger conventional instruments. These features made the instruments particularly desirable for use on ships. An excellent record of service has proved their value, and the experience gained during the war years has been the basis of further improvements.

Fig. 1. A new long-scale instrument, showing characteristic styling



General improvements which apply to the new instruments include:

(a). An increase of 10 degrees in scale angle (total scale length is 7.1 in.).

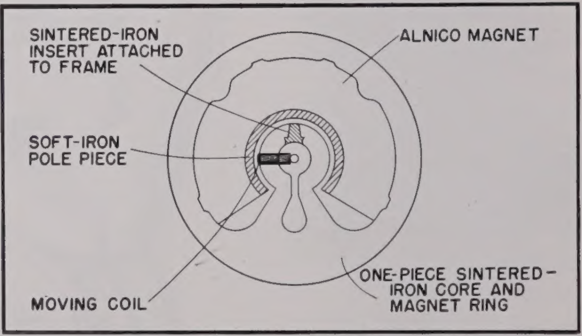

SINTERED-IRON INSERT ATTACHED TO FRAME
ALNICO MAGNET
SOFT-IRON POLE PIECE
MOVING COIL
ONE-PIECE SINTERED-IRON CORE AND MAGNET RING

Fig. 2. Basic elements of mechanism for d-c ammeters and voltmeters

(b). A more easily readable scale obtained by the use of new uniform-width numerals, horizontally arranged, and wedge-shaped accent marks at the numbered calibration lines. These permit rapid readings without confusion in associating the numerals with the proper point.

(c). Improved appearance obtained by a carefully styled plastic cover. A beveled window opening permits reading at sharp angles, and a center mask conceals the instrument mechanism and prevents any distraction from this source (**Fig. 1**).

(d). The use of spring-backed jewels which minimize pivot damage due to severe impacts.

In addition, many of the instruments have been made much easier to disassemble and repair, and some

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Material used in this paper was presented at technical sessions of AIEE Winter and Summer Conventions in 1947.

This article is so paged that, without mutilating other articles, it can be conveniently removed for separate filing by tearing out pages 14 to 19.—ED.

(1)"Design of Long-scale Indicating Instruments," by A. J. Corson, R. M. Rowell and S. C. Hoare, *Electrical Engineering* (AIEE Transactions), vol. 61, June 1942, p. 318.
"Advancements in the Design of Long-scale Indicating Instruments," by R. M. Rowell and N. P. Millar, *Electrical Engineering* (AIEE Transactions Abstract), vol. 66, Jan. 1947, p. 90.

have been made smaller in size. Improvements have also been made in performance characteristics. Dimensionally, old and new instruments of the long-scale wide-angle design are interchangeable.

The following description covers in more detail the features of various new instruments of this design.

D-c Ammeters and Voltmeters

A long-scale d-c instrument requires a magnet system with a long radial air gap of high flux density to provide adequate operating torque. Although this requirement was met in the previous design, it has been found possible to build a magnetic circuit assembly that provides a constant air gap under all conditions, increasing the permanency of calibration, making a more uniform scale distribution, and permitting disassembly for servicing or repair without changing scale distribution.

Fig. 2 shows the new magnet system. In this design the magnetic return path is made in a single piece which includes the central core and the outer ring. Pressed-powder metallurgy has made it possible to sinter this iron return path in a single mold.

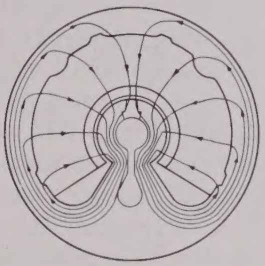

Fig. 3. Magnetic circuit, showing flux paths

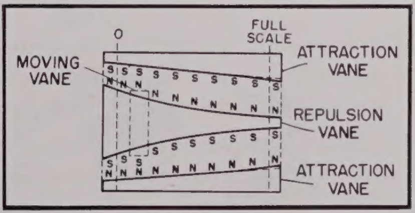

Fig. 4. Development of attraction-repulsion members for a-c voltmeters

Since the moving-system coil must encircle the central core, an opening must be provided to permit removal of the moving system. The opening in the central core is sufficiently wide for the moving coil to pass through; and the circular center opening, together with the elongated slot below it, permits the passage of the supporting frame when it is necessary to remove the frame and moving-system assembly for inspection or repair. The break in the magnetic core is made at a magnetic neutral point (**Fig. 3**) where the flux splits in two directions and thus has a minimum effect on the flux density and scale distribution. To minimize the scale-distribution effect, a piece of sintered iron is cast onto the frame to close this core opening when the frame and moving system are inserted.

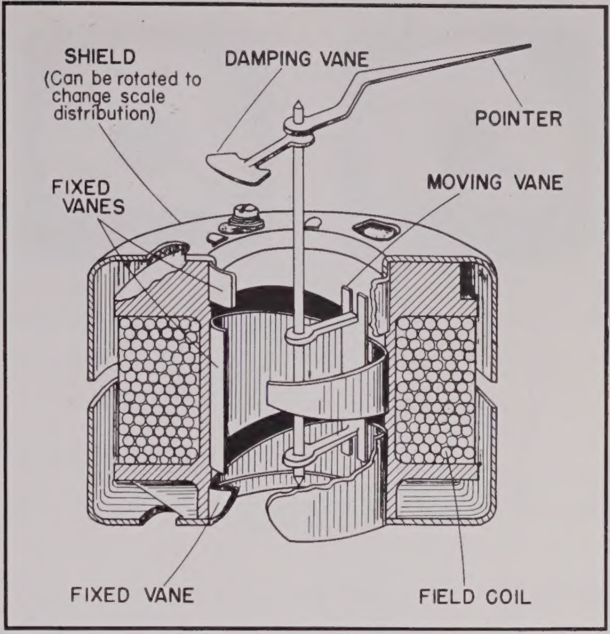

Fig. 5. Improved attraction-repulsion mechanism for a-c voltmeters and ammeters

A new method of resistance-card mounting has resulted in a decrease in depth because self-contained voltmeters do not now have the resistance cage formerly mounted on the rear of the instrument. Resistance cards are embedded in solventless varnish in a depression in the inside of the base. This effectively seals the resistor against damage and rapidly conducts away the heat developed in the resistor.

The new instrument has high torque and a relatively large torque-to-weight ratio and is inherently shielded against the effect of stray magnetic fields.

A-c Ammeters and Voltmeters

Experience has shown the attraction-repulsion iron-vane mechanism to be the simplest and most efficient type now in use for long-scale a-c ammeters and voltmeters. The continued use of this system has indicated it to be very stable, and possible improvements are chiefly in the control of scale distribution. The developed magnetic system (normally formed cylindrically inside a circular coil) is shown in **Fig. 4**. The dimensional relations and relative positioning of these four magnetic components determine to a great extent the scale distribution. Adequate control of these relations, therefore, is necessary to maintain the most readable and most closely matching scale distributions.

To obtain proper spacing between fixed and moving vanes, the radius of the latter is controlled by a one-piece vane and bracket punching. This construction not only results in a more uniform radius of operation, but also eliminates soldering and welding operations which may have detrimental effects on the magnetic properties of the vane.

The circular shape of the attraction members is maintained more accurately by the use of a drawn tubular section on the inside of the shields which hold them in position. The construction is shown in **Fig. 5**.

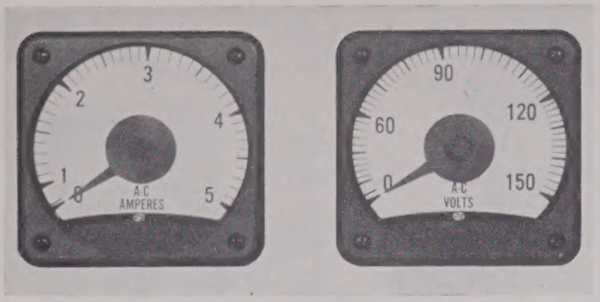

Fig. 6. A comparison of a-c ammeter and voltmeter scale distributions

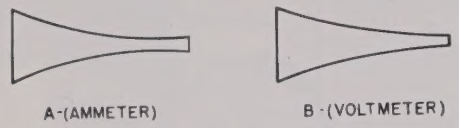

Fig. 7. Developed shapes of repulsion irons for (*A*) a-c ammeter and (*B*) a-c voltmeter

Slotting of the shield has been found unnecessary because of the high-resistance material being used, and errors from eddy currents have been found negligible up to 400 cycles. Considerable attention has been given to scale distribution; and the use of different repulsion-vane designs for the ammeter and voltmeter has made these instruments particularly suitable for their specific purposes. **Fig. 6** shows the ammeter and voltmeter scales. It will be noted that the ammeter is essentially uniform down to approximately 20 per cent of full-scale value, whereas the voltmeter is more constricted at the lower end in order to permit the widest scale in the region normally used. The two repulsion members are shown in **Fig. 7**; and it will be noted that the one used on the ammeter has the steeper slope at the zero (wide) end, which tends to open up the distribution in this region.

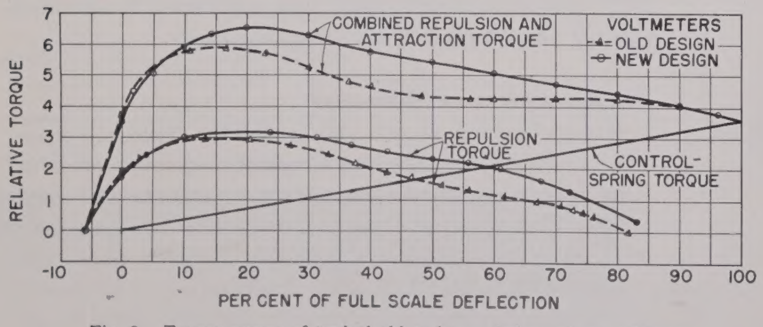

Fig. 8. Torque curves of typical old and new designs of a-c voltmeter

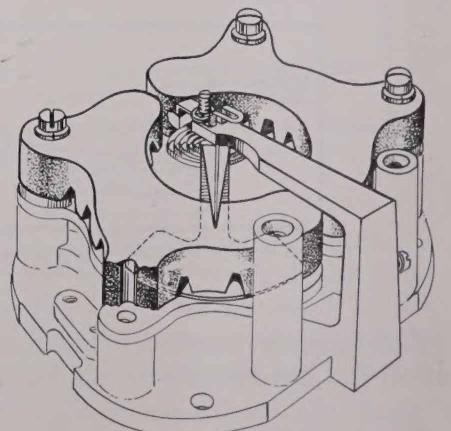

Fig. 9. Cutaway section of magnetic damping system

To permit a more accurate control of scale distribution and a closer matching of instrument scales, the full-scale ends of the attraction members have been given an increased slope which results in greater sensitivity of this adjustment. These modifications, together with the positive positioning of the attraction vane against the end of the field coil, and the use of a molded field coil having the repulsion vane as an insert machined to very close tolerances, facilitate the duplication and control of scale distribution to a large extent and result in a straighter torque curve, as shown in **Fig. 8**.

Damping of all a-c instruments of the new design is accomplished by two semicircular multipole alnico magnets which set up eddy currents in a segmental aluminum disk carried by the moving system. The alnico magnets are cast with grooves to separate the ten pole faces (**Fig. 9**) and are magnetized by looping a conductor around through the grooves as shown in **Fig. 10** and passing through this conductor a d-c impulse of short duration. This produces alternate north and south poles. The return flux path is made through a soft steel plate beneath the disk.

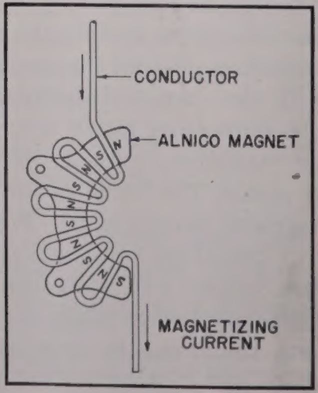

Fig. 10. Diagram of method of magnetizing damping magnets

Wattmeters and Varmeters

Since both wattmeters and varmeters use an iron-cored electrodynamic type of mechanism, they must have long air gaps and are therefore subject to the same problems that apply to d-c instruments. The new design, therefore, deals with the control of scale distribution as well as improvements in accessibility and stability. A new field circuit is shown in **Fig. 11**. It utilizes a one-piece laminated core and return path with a fixed air gap. The laminations are punched from a new silicon strip steel which permits high flux density with low hysteresis and are cemented together with a solventless varnish under heat and pressure. The use of rivets is eliminated, except those required to attach the field assembly to the bracket, thus reducing eddy currents. The field coil itself is cast in a solventless varnish, mak-

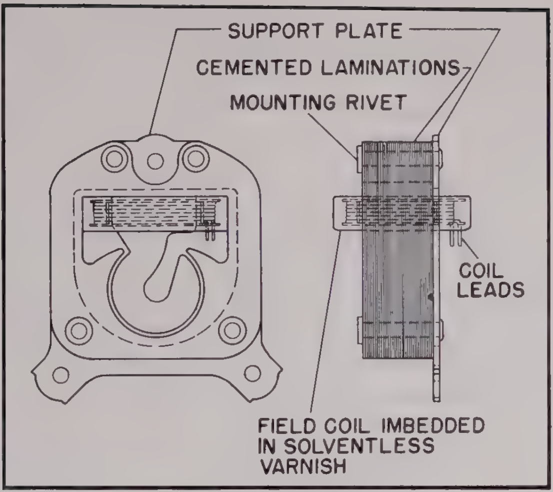

Fig. 11. Magnetic circuit of wattmeters and varmeters

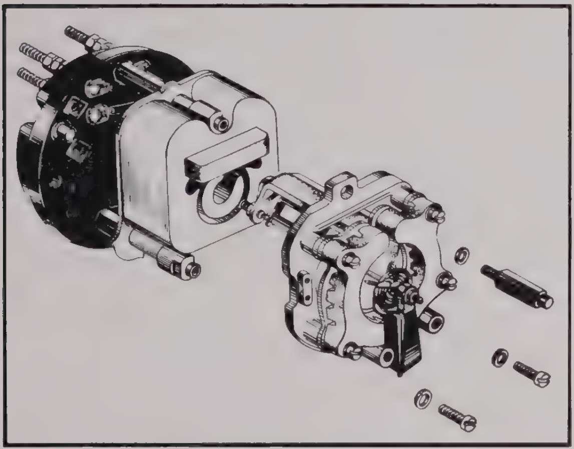

Fig. 12. Expanded sketch indicating method of removing wattmeter frame and moving system

ing a rigid assembly which cannot be easily damaged and which, because of its high thermal conductivity, effectively dissipates the heat of the coil.

The new field and moving system have a much higher torque-producing effectiveness than the previous design, resulting in a higher total torque and torque-to-weight ratio with smaller size, lighter weight, increased overload rating, and lower volt-ampere burden.

Mechanical improvements have made the instrument capable of being easily disassembled for repair or maintenance. **Fig. 12** shows how the frame and moving system can be removed through the opening in the hook-shaped core, without disturbing the magnetic circuit, by simply unsoldering two leads and removing a few screws which attach the supporting frame and the damping magnets to the base.

The smaller mechanism has made room for the potential circuit resistors inside the case and thus reduces the total instrument depth.

Power-factor compensation has been provided in the form of a capacitor shunting the moving coil and part of the series resistor to reduce the effect of the potential circuit inductance and the iron losses in the instrument.

Compensation has also been applied to reduce the tendency to deflect slightly when potential alone is applied, as is common to mechanisms of this type. The tendency is due to a solenoid effect in which the coil moves in such a direction as to link the greatest possible amount of flux. This effect has been practically eliminated in the new design by means of a compensating winding in series with the moving coil and connected in such a direction as to oppose the upscale deflection. Since both the solenoid effect and that of the compensating coil increase with voltage, correct compensation is obtained at all voltage values within the rating of the instrument. Compensation for both power factor and voltage creep are shown in the schematic connection diagram, **Fig. 13**.

Power-factor Meters

The power-factor meters of the long-scale wide-angle design make use of the rotating-magnetic-vane principle. Two magnetic vanes are mounted on opposite sides of the shaft about one inch apart and are connected magnetically by a nickel-iron sleeve. This moving-vane system is polarized by a stationary current coil surrounding the center sleeve; the complete assembly with its supporting plastic frame is set inside a polyphase motor-type stator. The stator is excited from line potential with its current limited by a series resistor.

Power-factor meters are unique in that their readings should be independent of variations in both current and potential, assuming the phase angle to remain constant. Usually the small voltage variations encountered do not disturb the accuracy of these instruments seriously, but since the circuit current may vary as much as 5 or 10 to 1, there is usually considerable effect on instrument accuracy. In the conventional electrodynamic type, the torque exerted by the conducting spirals is sufficient to make the instrument partially current-responsive. While the rotating-magnetic-vane type has no spirals, a small torque due to potential alone is set up in a manner that may be described as hysteresis-motor action. The effect of this extraneous torque will vary with the instrument torque and consequently produces the greatest errors at low current values, where it becomes an appreciable portion of the total torque. In the previous design, these errors were reduced to a low value by the use of well annealed nickel-iron alloys.

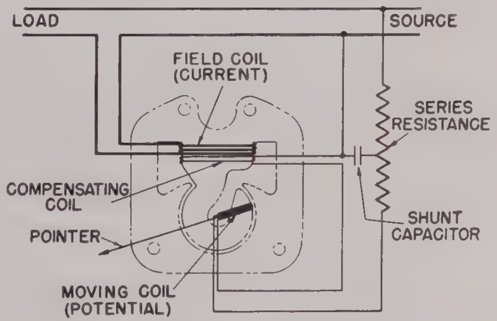

Fig. 13. Connections for power-factor and voltage compensation

In the new design, this hysteretic drag, and consequently the current error, has been greatly reduced by changing the shape of the moving vane to that shown in **Fig. 14** and also by a selection of the optimum ampere-turns in the stator. This new vane, because of its shape, saturates at a lower flux density and thus gives a flatter torque curve than that of the old design, as shown in **Fig. 15**. This shows the torque value to be nearly constant from two to five amperes.

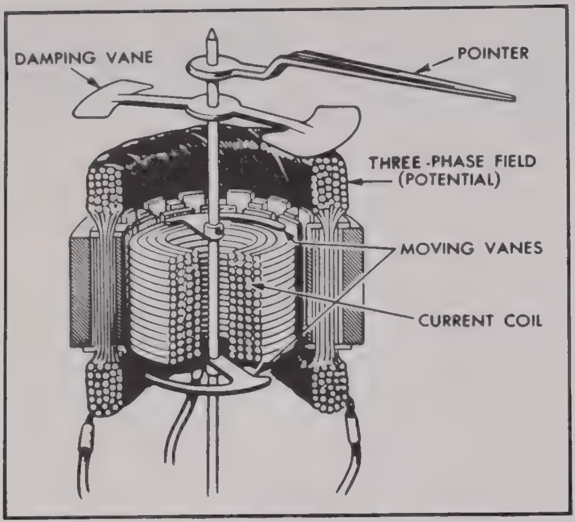

Fig. 14. New power-factor-meter mechanism

By proper selection of ampere-turns, a balance between the hysteresis torque and other extraneous torques is obtained, and the current errors between 1- and 5-amp readings are thus reduced to a fraction of their former values.

It will be noted that in the new design the torque of the instrument has been slightly reduced at the rated current of five amperes. However, the weight of the moving system has been reduced at the same time so that approximately the same torque-to-weight ratio is obtained. Moreover, the torque value at low current ranges—such as one ampere—has been materially increased, thus providing more uniform operation and damping over the entire operating range and permitting instrument use down to lower values of current than were previously considered within the accuracy range.

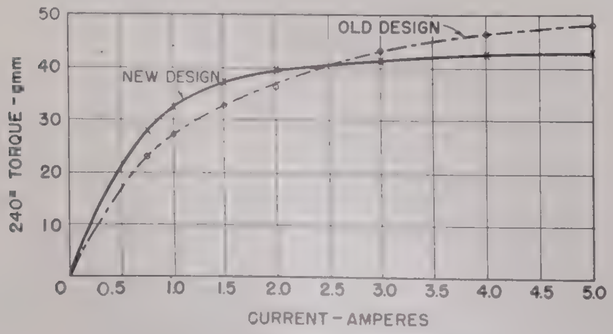

Fig. 15. Power-factor-meter torque curves

Synchroscopes

Synchroscopes also make use of the rotating-magnetic-vane principle. Their construction is similar to that of the power-factor meter except that the exciting coil used to polarize the vanes is wound for potential instead of current. In accordance with the present-day practice, these instruments are designed for single-phase operation so that they may be used universally on either single-phase or polyphase circuits. Single-phase operation has usually been accomplished by means of a phase-splitting network in the form of an external impedor. In the new design, the instrument is entirely self-contained since an internal resistance-capacitance network provides the necessary phase displacement to obtain a rotating field in the motor-type stator. This is shown schematically in **Fig. 16**. To obtain a lagging current I_2 in the stator coil No. *2* having the same magnitude but 90 deg out of phase with the current in stator coil No. *1* (I_1), a capacitor C_2 is connected in series with the No. 2 stator coil. This causes the current I_2 to lead the voltage V, but in operation the current is reversed (shown by $-I_2$) so that it actually lags the voltage. For testing and adjusting purposes, some means of control is necessary. This is provided by the adjustable resistance R_2. The capacitor C_1 serves to insure the proper phase angle as well as the magnitude of the phase shift of current I_1 in stator coil No. *1* when R_2 is adjusted in test. This provides a very simple and convenient means of adjustment.

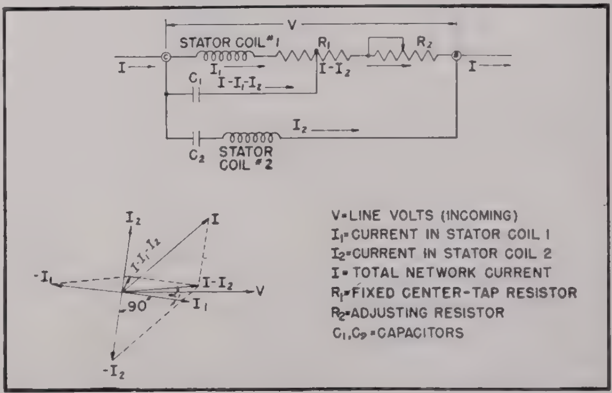

Fig. 16. Schematic and vector diagrams of new synchroscope-stator circuit

The elimination of the external impedor has resulted in an appreciable saving in panel space, and the reduction in the number of instrument terminals has simplified wiring. The standard instrument now has four terminals in order to completely isolate the two circuits from the incoming and running machines.

Frequency Meters

The latest design of frequency meter operates on a new principle which could be described as a mutual-inductance principle.(2) In construction it is similar to the single-phase wattmeter except that it has a field wound for potential instead of current. With this field coil excited, a voltage is induced in the moving coil, the magnitude of which depends upon its angular position and, consequently, the position of the pointer on the scale. The moving coil is connected so that its induced voltage opposes the voltage drop across a resonant circuit which varies with the frequency. Schematic connections are shown in **Fig. 17**.

---

(2) "Applications of the Electrodynamic Instrument Mechanism," by A. J. Corson and N. P. Millar, *Electrical Engineering* (AIEE Transactions Abstract), vol. 66, June 1947, p. 610.

A difference between these two voltages will result in a flow of current through the moving coil. This will be acted upon by the field in such a manner as to produce a deflection of the moving system. This deflection of the moving coil will continue until the in-phase component of the moving-coil current is reduced to zero. Thus for each frequency value there is a definite voltage drop across the impedance network matched by a given value of induced moving-coil voltage which occurs at only one scale position. Since there are no control springs, equilibrium is established at these points, and the instrument may thus be calibrated in terms of frequency.

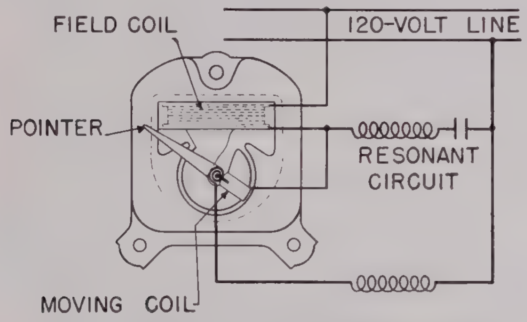

Fig. 17. Schematic connections of frequency meter

With this simplified construction the use of a separate "restoring mechanism" has been eliminated, resulting in smaller size, simplified calibration, and in greater ease of maintenance and repair.

Summary

Having proved its value during the war years, the 250-deg long-scale instrument is now finding increased industrial and central-station applications. Modifications in design have improved the performance characteristics, the ease and permanence of calibration, and accessibility for inspection or repair. Changes in cover design have been functional, resulting in better readability and improved appearance. The Cover shows a typical switchboard panel utilizing these instruments.

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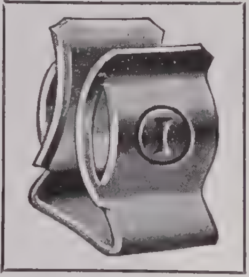

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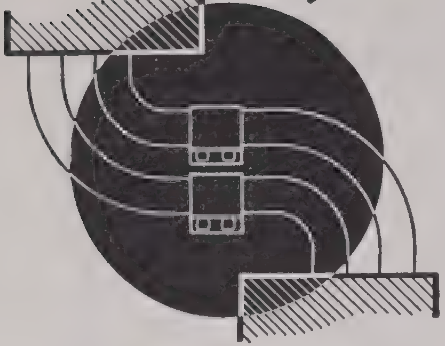

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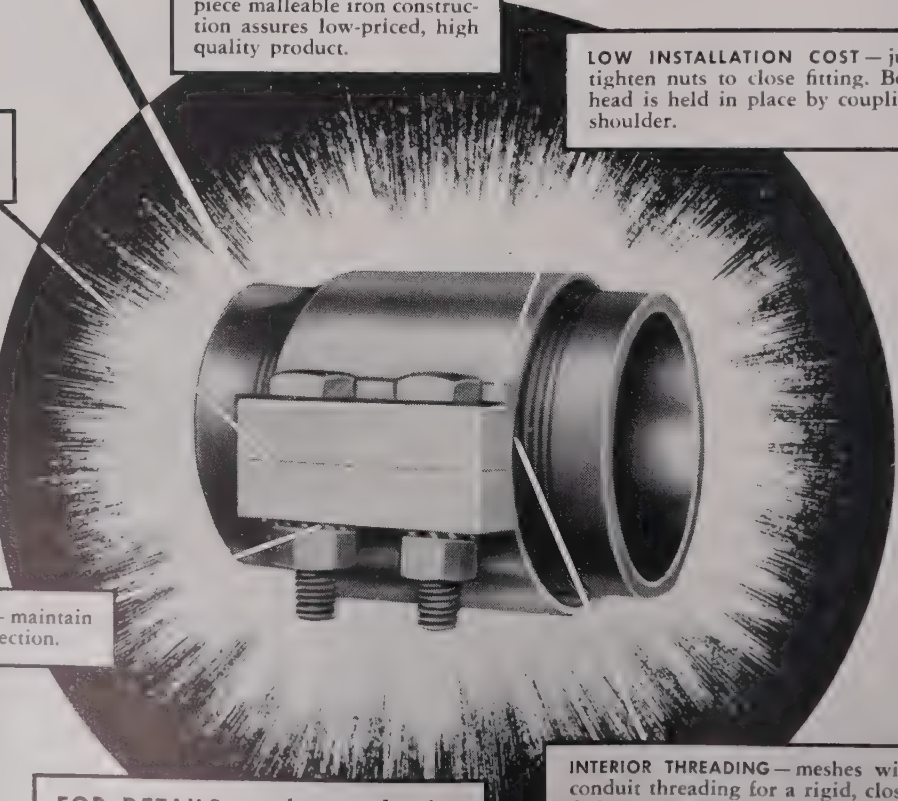

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WOUND-ROTOR MACHINE OPERATION

Hal Gibson

Compact analysis of motoring and generating action in adjustable-speed drives. Correlation of electric power, mechanical power, and electrical and mechanical speeds

By HAL GIBSON
Industrial Engineering Divisions
Apparatus Department, General Electric Company

DEMANDS for adjustable-speed a-c drives have resulted in an increasing use of systems utilizing wound-rotor machines. Such systems may be of the simpler type involving only a wound-rotor induction motor and secondary control, or the systems may be more complex, using wound-rotor motors and means whereby the secondary or slip power can be fed back into the constant-frequency bus. Other systems may employ the wound-rotor machine as a frequency changer for use in adjustable-frequency adjustable-speed a-c drives.

Because of this increased use of wound-rotor machines, a review of them with respect to the relationships between primary and secondary electrical power, mechanical power, and the electrical and mechanical speeds in a simple manner is of interest to a large number of engineers.

Consideration will be given first to a wound-rotor machine operating with one winding connected to a constant-frequency bus. The operation will be divided into three regions of speed:

(1). Where the machine rotor moves in the same direction of rotation as the magnetic revolving field of the stator, but at a lower speed. In this region the rotor speed lies between zero and synchronous speed, and the slip of the rotor is positive and is equal to or less than synchronous speed.

(2). Where the machine rotor moves in the same direction of rotation as the magnetic field of the stator but at a greater speed. For this condition the slip of the rotor is negative, and may have any magnitude.

(3). Where the rotor moves in a direction opposite the direction of rotation of the stator magnetic field. Here, the slip of machine is positive and equal to or greater than synchronous speed.

The *three fundamentals* to remember are:

(1). The sum of all of the power inputs into the machine is equal to the sum of all the power outputs, neglecting losses.

(2). The algebraic sum of the rotor mechanical and electrical speeds is equal to stator electrical speed, or, the algebraic difference between rotor mechanical and stator electrical speed equals rotor electrical speed.

(3). The mechanical torque on the rotor is equal to the electrical torque of the stator magnetic field. The electrical torque on the rotor is also equal to the rotor mechanical torque and to the stator electrical torque.

For the purposes of this article, all considerations are based on the *per unit* system, with synchronous speed assumed equal to unity and the power input into the constant-frequency winding also assumed equal to unity.

Power flow out of the shaft is defined as motoring operation, and power flow into the shaft of the machine is defined as generator operation.

All losses are neglected.

Power into the machine is considered positive, and power out of the machine, either electric or mechanical, is considered negative. Rotations in the clockwise direction are positive; rotations counterclockwise, negative.

The fixed-frequency-field* electrical speed w_s is, for these considerations, the speed of the stator magnetic

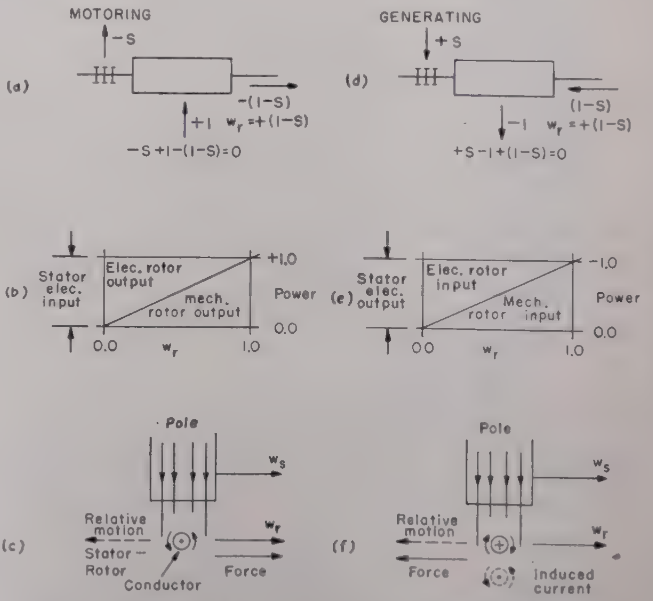

Fig. 1. Operation of the wound-rotor type machine with positive mechanical rotation below synchronous speed

(+) w_s = stator electrical speed = unity (line frequency); electric power at the stator is also assumed equal to unity
(+) S = slip, the rotor electrical speed; equivalent to electric power at the collector rings
(+) w_r = rotor mechanical speed = $(1-S)$; equivalent to mechanical power
(+) and (−) = direction of power flow and direction of rotation; (+) indicates power flow into the machine, and indicates clockwise rotation

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This article is so paged that, without mutilating other articles, it can be conveniently removed for separate filing by tearing out pages 22 to 25.—Ed.

* With regard to the operation of the wound-rotor machine under any of the conditions outlined in this article, either the rotor, the moving part of the induction machine, or the stator could be connected to the line or the fixed-frequency source of power, and similar operations would result.

field and corresponds to line frequency in cycles per second. With operation from a constant-frequency bus, both stator-field speed and line frequency are assumed to be unity.

The slip S, electrical speed of the variable-frequency field, corresponds to the difference between the stator-field speed and rotor mechanical speed w_r.

Positive Rotation Below Synchronous Speed

For Motoring

Fig. 1[†] covers operation of the machine in the first region, corresponding to mechanical speeds between 0 and 1.0 and slips between 1.0 and 0.

Figs. 1(a), 1(b), and **1(c)** refer to motoring operation, in which mechanical *power output* from the shaft is obtained. **Fig. 1(a)** shows the flow of power into and out of the machine, indicating the per unit power into the stator from the line, out of the collector rings as electric power, and out of the shaft as mechanical power.

Fig. 1(b) indicates this graphically, with the positive power being referred to the input into the machine.

As the electrical torque on the stator and the rotor are equal, and also equal to mechanical or shaft torque, the three components of power are, as indicated in **Fig. 1(b)**, directly proportional to the electrical speed of the fixed-frequency field frequency, rotor electrical speed (slip), and rotor mechanical speed.

Fig. 1(b) shows the division of power at any speed. For instance, at one-third speed the stator power input passes out of the rotor as 0.33 per unit mechanical power and 0.666 per unit electrical power at a frequency equal to 0.666 per unit line frequency. This is true irrespective of the power input into the stator.

Fig. 1(c) represents a simple diagram of the forces between the stator field poles and a single conductor or side of a coil of full-pole pitch. Although the poles rotate in the same direction as the rotor, the relative motion between the stator field and the rotor are in the opposite direction. Thus the induced voltage and current (neglecting the reactance of the coil) are as indicated. Consequently the force produced on the conductors by the currents flowing in the rotor conductors and the magnetic field is in the same direction as the motion of the stator rotating field; therefore mechanical rotation is in that direction, and the machine is motoring.

For Generating

Figs. 1(d), 1(e), and **1(f)** are for the wound-rotor induction machine operating through the same speed ranges as already presented in **Fig. 1** but being driven externally by another motor. Here it will be noted in **Fig. 1(d)** that excitation at slip frequency must be applied to the rings (power flow in) and that the rotor must be driven mechanically at a speed corresponding to the difference between the stator frequency and the slip frequency applied to the rings. Under this condition, the power flows in at the rings, also in at the shaft, and out through the stator to the line. **Fig. 1(e)** indicates graphically the division of power between the rotor electrical power, rotor mechanical power, and stator power at different rotor speeds.

Fig. 1(f) indicates the forces on the conductor due to the currents flowing in it. The rotor is driven in the same direction as the rotation of the magnetic field, and the relative motion is in the direction of that for motoring. However, current is forced through the conductor in the direction opposite to the induced voltage. Consequently the force on the conductor caused by the action of the current and the field is in the direction opposite to that of rotation; this results in the conventional feedback of power back to the line.

Positive Rotation Above Synchronous Speed

For Motoring

Figs. 2(a), 2(b), and **2(c)** apply to the motoring conditions in the speed range above synchronous speed. **Fig. 2(a)** indicates the flow of power into and out of the machine, with power flowing into the collector rings at slip frequency and into the stator at line frequency; the sum of these two emerges as mechanical power at speeds above synchronism. **Fig. 2(b)** indicates this in a graphical manner, showing the proportionate amounts of rotor electrical, rotor mechanical, and stator electrical power at various rotor speeds.

Fig. 2(c) indicates the forces on the conductor, the relative motion of the conductor and the stator fields, the direction of the stator-field rotation and the direction of the mechanical rotation of the rotor. In this case

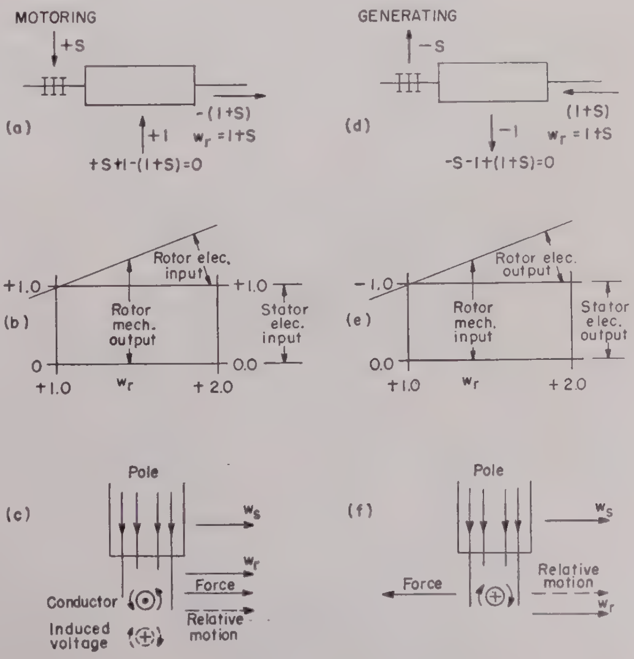

Fig. 2. Operation of wound-rotor machine with positive mechanical rotation above synchronous speed

(+) w_s = stator electrical speed = unity (line frequency); electric power at stator assumed equal to unit

(−) S = slip, the rotor electrical speed; equivalent to electric power at the collector rings

(+) w_r = rotor mechanical speed = $(1-S)$; equivalent to mechanical power

(+) and (−) = direction of power flow and direction of rotation; (+) indicates power flow into the machine, and indicates clockwise rotation the slip-frequency current is in opposition to the induced voltage of the conductor resulting from the rotation of the field poles past the conductor.

[†] Fig. 1 and the subsequent illustrations are merely indicative of machine operation; and losses are not considered or indicated in the illustrations.

The solid lines in **Fig. 2(c)** indicate actual current flow and flux direction, and the dotted lines show the directions of induced voltages. However, the force on the conductor is in the same direction as rotation; consequently this is a motoring condition. Since the slip is negative, the power flows out of the shaft.

For Generating

Figs. 2(d), 2(e), and **2(f)** refer to the operation of the machine when considered as a generator or when it is being driven by a motor or other device above synchronous speed. **Fig. 2(d)** shows that the power input flows out of the collector rings at slip frequency and back into the line at stator frequency. The machine operates at a speed corresponding to the sum of the collector-ring frequency and the stator frequency. **Fig. 2(e)** also shows the division of power between the collector rings and the stator and the power input from the shaft.

It will be noted that, in **Fig. 2(f)**, the mechanical rotation of the rotor is opposite in direction to the force on the rotor due to the interaction of the rotor current and the stator field.

Negative Rotation

For Motoring

Here the induction machine is operating with a positive slip greater than, or equal to, unity, and the mechanical speed is negative or zero. For the motoring condition, shown in **Figs. 3(a), 3(b),** and **3(c)**, power enters the collector rings at slip frequency and comes out of the stator at line frequency and out of the shaft as mechanical speed. **Fig. 2(b)** shows graphically the division of power at different rotor speeds between stator output, mechanical shaft output, and the electrical rotor input.

Fig. 3(c) indicates that the mechanical rotation is in the same direction as the mechanical force on the conductor produced by the interaction between the magnetic field and the current in the rotor. However, the current flow indicating power input into the collector rings is in opposition to the induced voltage in the conductor resulting from the relative rotation of the stator magnetic field and the rotor. The same convention holds in regard to the relative motion, in that the rotor conductors are considered stationary and the stator moving, which is true with regard to the internal induced voltage in the conductors.

For Generating

Figs. 3(d), 3(e), and **3(f)** refer to the condition of the machine operating as a generator, or with mechanical power input into the shaft. Here power flows into the machine mechanically through an external motor driving the machine against the rotation of the magnetic field of the stator; and power also flows into the machine from the line. Power flows out electrically from the collector rings at a speed corresponding to a slip frequency greater than unity and is proportional to motor speed, as indicated in **Fig. 3(e)**. With power input to the stator being positive, the positive power input from the stator and from the shaft is, of course, negative power output from the collector rings.

Fig. 3(f) is the force diagram and shows that the rotation of the rotor is in opposition to the force generated between the current in the rotor conductors and the magnetic field of the stator. However, the current flows in the conductors in the direction of the induced voltage produced by the magnetic field of the stator cutting the rotor conductors. This, then, is generator action, from the standpoint of the mechanical power input into the machine and the standpoint of the conductors on the rotor.

Although the machine can run either above or below its synchronous speed, it could not run as a motor at synchronous speed, as might be inferred, unless some form of d-c power was fed to the rotor in such a manner as to excite it with the north and south poles which it would have at slip frequency. This method of operation is employed in some instances, and the machine is then called a synchronous induction motor. The diagrams indicating no power input to the rotor do not consider the necessary power for excitation of the rotor under the condition of synchronous operation.

Constant Rotor Speed with Adjustable Frequency on Both Rotor and Stator

The rules set up for construction of **Figs. 1, 2,** and **3** can be applied also to the condition of adjustable rotor and stator frequency. **Fig. 4(a)** shows a wound-rotor induction machine operating at constant rotor me-

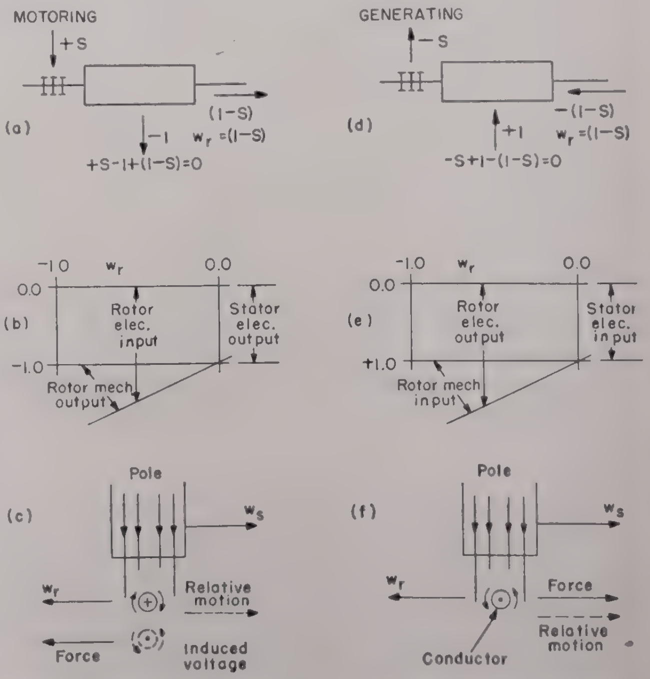

Fig. 3. Operation of wound-rotor operation with negative mechanical rotation

(+) w_s = stator electrical speed = unity (line frequency); electric power at stator assumed to be unity

(+) S = slip, the rotor electrical speed; equivalent to electric power at the collector rings

(−) w_r = rotor mechanical speed = $(1-S)$; equivalent to mechanical power

(+) and (−) = direction of power flow and direction of rotation; (+) indicates power flow into machine, and indicates clockwise rotation chanical speed equivalent to 30 cps with an adjustable frequency of 0 to 30 cps input into the collector rings *c*. What is direction of power flow at the shaft *a* and stator *b* if rotor electrical speed is in the opposite direction of rotation as the mechanical speed?

As both frequencies on the rotor are added algebraically to determine stator frequency, this frequency will be:

$$f_s=(1-S)$$

where S = slip frequency at collector rings *c*. Constant mechanical rotor speed = 1.0.

And, as the torques are equal for all three speed elements, the power is: P_c (collector rings), proportional to S; P_a (shaft), constant; P_b (stator), proportional to $(1-S)$.

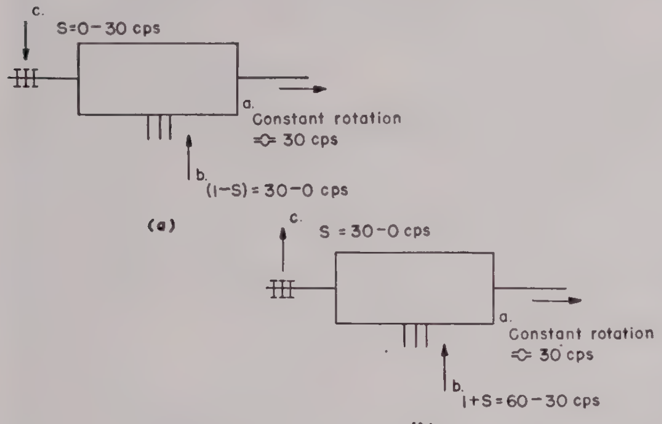

Fig. 4. Operation with constant mechanical rotation and adjustable frequency at both stators and collector rings

$(\pm)$ S = adjustable-frequency supply input at collector rings *c*
$(+)$ *a* = constant mechanical rotation at rotor shaft *a*
$1+(\pm S)$ = adjustable frequency supply at stator *b*

The power flow will be in at the collector rings *c*, in at the stator *b*, and out at the shaft *a*, since the sum of all the components of power in must equal the sum of the component of power flowing out of the machine.

Similarly, for **Fig. 4(b)**, with the rotor running at constant mechanical speed equivalent to an electrical speed of 30 cps, power is to flow out at collector rings *c* at frequencies of 30 to 0 cps, and the electrical speed of the rotor is to be in the same direction of rotation as rotor mechanical speed. The frequency at *b*, or stator, will be:

$$f_s=(1+S)$$

Adding rotor electrical and mechanical speeds algebraically, the power will be: P_b (stator), proportional to $(1+S)$; P_a (shaft), constant; P_c (collector rings), proportional to S.

Power will flow into the stator *b*, out at the shaft *a*, and out at the collector rings *c*.

Thus it is seen that the power is proportional to the speed. The rotor electrical and mechanical power will flow in the same direction as their speeds, with respect to each other. That is, if rotor electrical and mechanical speeds are in same direction, both components of rotor power will be either into or out of the rotor; if the rotor speeds are in opposite directions, the power flow will be: one component into the rotor; the other component out of the rotor.

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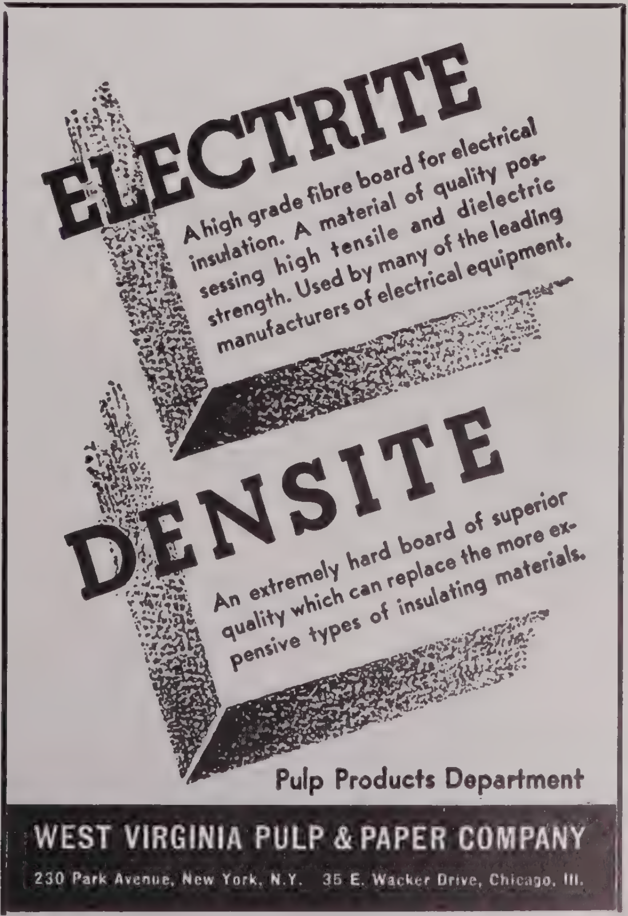
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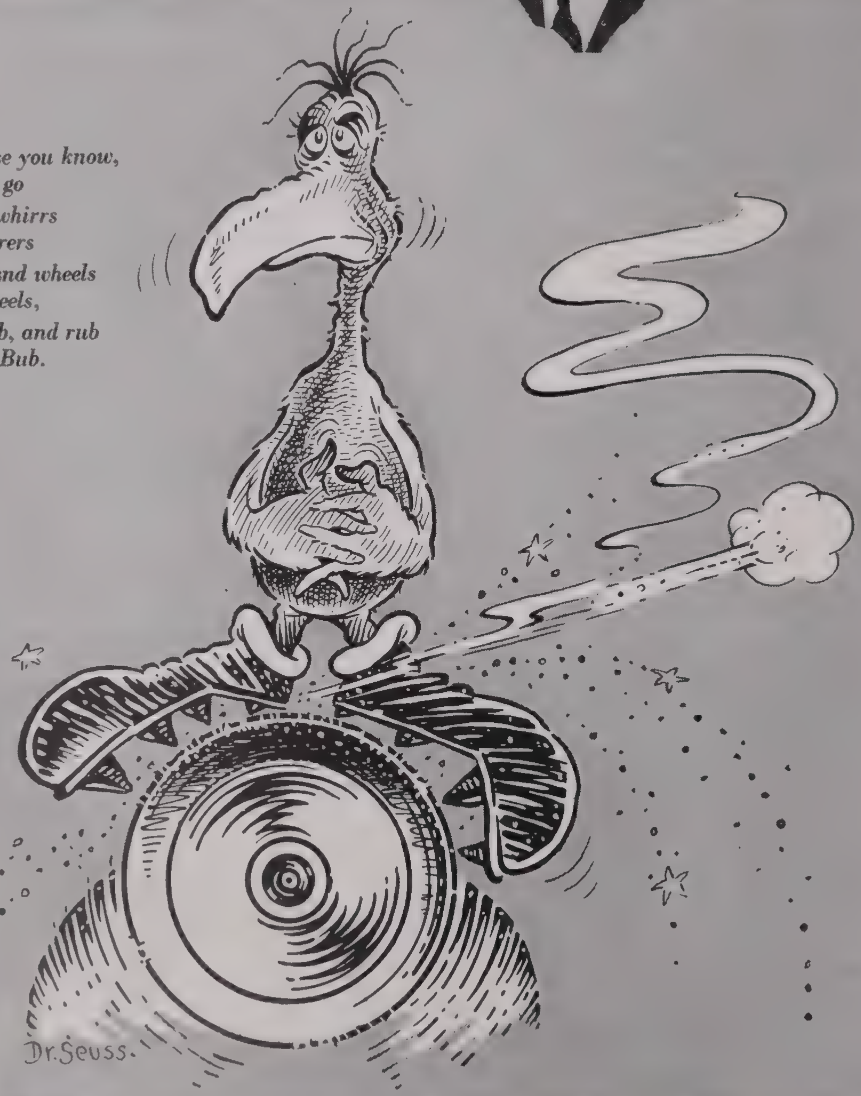
To places where machinery whirrs
And frustrate man-u-fact-u-rers
By bearing down on shafts and wheels
With his abrasive toes and heels,
Which rub, and rub, and rub, and rub
And rub away your profits, Bub.



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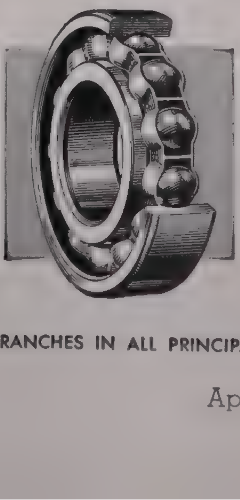

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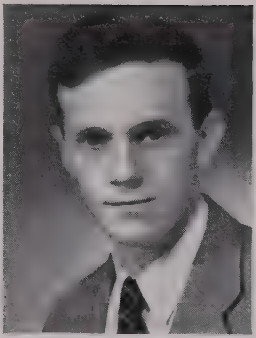
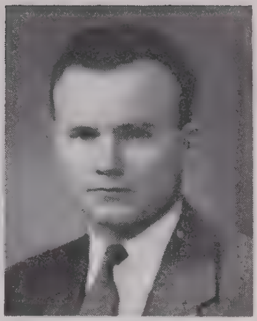


John G. Hutton

ELECTRIC POWER SUPPLY PROTECTION ON AIRCRAFT

The trend toward more electrical operations, plus growth in airplane size, has greatly increased requirements. Reliability is essential



Paul C Bogiages

By DR. J. G. HUTTON and P. C. BOGIAGES
General Engineering and Consulting Laboratory
General Electric Company

ELECTRICAL short circuits in aircraft first became a serious problem in the early years of World War II with the advent of the four-engined airplane and the subsequent rapid increase in electric-power requirements. Since that time much study has been given to the problem, and various means developed for the protection of aircraft electrical circuits and equipment. Some of these means were considered individually in a series of articles(1); it is the purpose of this article to consider the over-all problem of eliminating electrical fire hazards in aircraft and to present results of actual tests of protective equipment.

Aspects of High-current Faults

In the early days of large aircraft, little was known of the effects of high-current short circuits and whether these could be relied upon to be self-clearing. A considerable amount of experimental work was performed by various investigators,(2),(3) and at the outset two major facts came to light:

(1). That with high energy concentration at the short circuit, a fault will be self-clearing but accompanied by scattering of molten metal globules over a considerable area (**Fig. 1**).

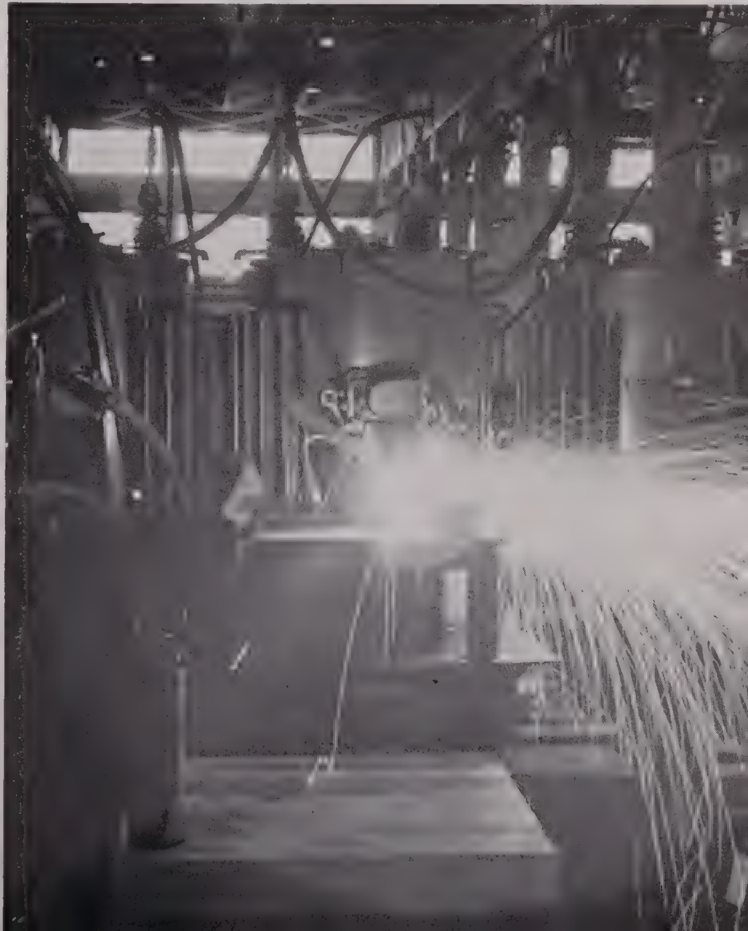
(2). That with low energy concentration at the short circuit, a permanent contact between the conductor and airplane structure may result.

Results of tests showed that self-clearing faults were predominant on a statistical basis, although the range of clearing time was from the minimum of 0.05 sec to the maximum of 2.5 sec, with a median value of approximately 0.6 sec. It was therefore evident that a short circuit could not be relied upon wholly to clear itself within a time short enough either to prevent structural damage or, more seriously, to avoid fires. This conclusion was arrived at independently by investigators(2),(3) using mock-up electric systems and from investigations carried out on the B-29 and B-32 airplanes. In addition, it was found that a short-circuit resulting in permanent contact between the conductor and airplane structure would disturb the entire electric system and thus interfere with control of the plane.

In many instances a self-clearing fault is more dangerous than a welded fault, since it is accompanied by arcing, extremely high temperatures, and showers of molten metal. This type of fault develops when only a few strands of the cable touch the airplane structure; with this condition, the concentration of energy is extremely high and causes the metals to melt and an arc to strike. Arcing continues until the structure is perforated or the cable melts away from the point of contact.

When the area of contact is great, the concentration of energy is comparatively low. Consequently there is only a limited amount of melting of the cable, and no arc occurs, but the cable may become welded to the frame. The fault is then continuous, with resultant disturbance of the entire electric system. Examples of

Fig. 1. Cable-fault test in which the high energy concentration scattered molten globules and resulted in a self-clearing fault



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(1)"D-c Power Systems for Aircraft," by H. J. Finison and R. H. Kaufman, Sept., Oct., Nov., Dec. 1945, pp. 22, 35, 59, 56; Mar., May, June, Aug., 1946, pp. 51, 46, 46, 41.

(2)"Electric-Circuit Burning-Clear and Damage Phenomena on Aircraft Structures," by C. M. Foust and J. G. Hutton, *AIEE Trans.*, Vol. 63, 1944.

(3)"A-c and D-c Short-Circuit Tests on Aircraft Cable," by J. C. Cunningham and W. M. Davidson, 961-9, *AIEE Trans.*, Vol. 63, 1944.

This article is so paged that, without mutilating other articles, it can be conveniently removed for separate filing by tearing out pages 27 to 32.—ED.

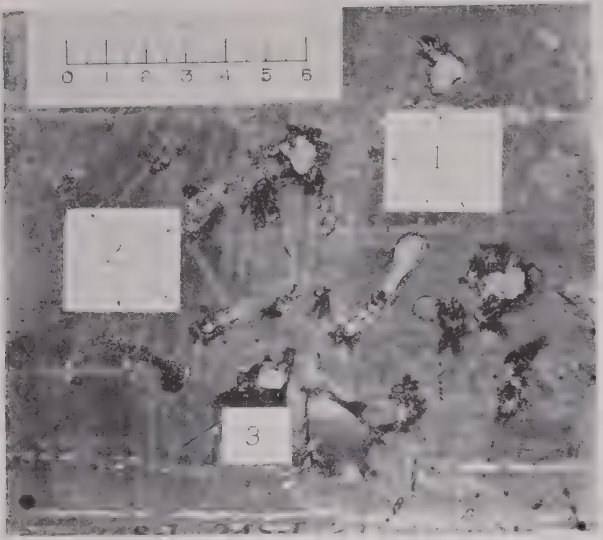

Fig. 2. Damage to a 24ST aluminum plate resulting from arcing and from bolted faults. Groups *1* and *3* were caused by the arcing from frayed cable which cleared themselves by burning through the plate

damage to a 24ST aluminum plate are shown in **Fig. 2**. Groups *1* and *3* were caused by arcing faults (frayed cable) which cleared themselves by burning through the plate.

On large airplanes, with electric systems of high-ampere capacity, there is more likelihood that faults will be self-clearing. **Fig. 3** is an oscillogram of a fault from which heavy arcing resulted, but which burned clear in 1.33 sec. The intensity of the arc and the area affected by scattered particles is illustrated in **Fig. 1**.

Preventive Measures

The best means to forestall a short circuit are frequent inspection of wiring and connections, proper handling and stowage of luggage and freight, care in handling tools, and primarily, proper training of maintenance personnel. Having exercised every precaution to preclude the possibility of a fault condition, it is then necessary, in view of the foregoing considerations, to provide adequate protection should a fault develop.

Protection Devices

To accomplish the isolation of the faulted circuit while permitting the remainder of the system to continue operating with a minimum fluctuation of voltage, protective devices must be selective and quick-acting. Delay in clearing short circuits results in reduction of system voltage to an extremely low level, thus depriving the system of considerable power (**Fig. 3**). Relays and contactors may fall open because of low voltage on their closing coils. This action could cripple the entire electrical system of the plane.

Protection methods may incorporate the use of fuses and circuit breakers of various types. In general, fuses are less satisfactory than circuit breakers because of their operating time characteristic and because they

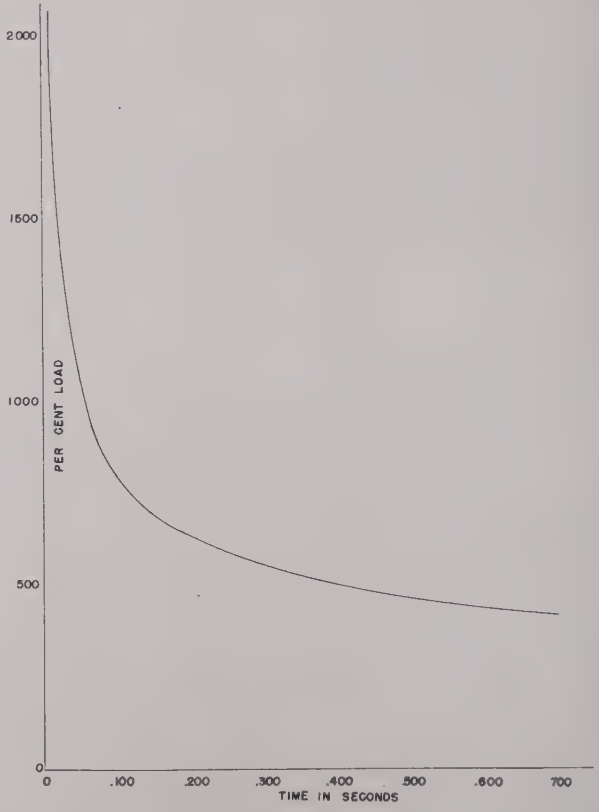

Fig. 4. Characteristics of a typical overcurrent breaker

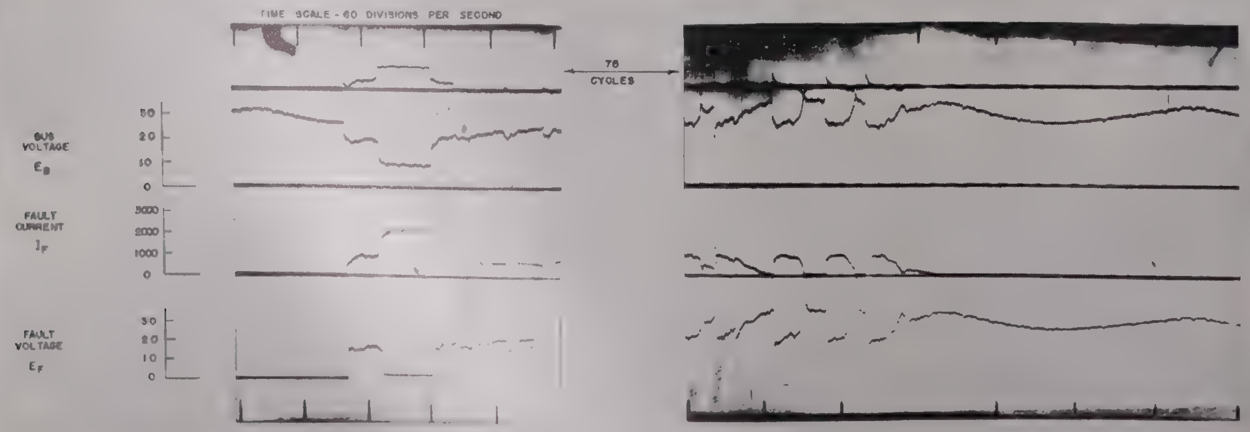

Fig. 3. Oscillogram of voltage disturbance resulting from heavy arcing; the fault burned clear in 1.33 sec

must be replaced after one operation. Today's practice shows a preference for circuit breakers rather than fuses.

Nondirectional overcurrent circuit breakers are available in both the thermal and magnetic types; both have inverse-time characteristics and serve for many purposes. Characteristics of a typical overcurrent breaker are shown in **Fig. 4**. Reverse-current breakers have particularly wide applications in protective systems. The reverse-current circuit breaker is illustrated in **Fig. 5**; its characteristics are shown in **Fig. 6**. It is used principally in the generator circuits between the generator relay and the positive bus, as shown in **Fig. 7**. When a fault occurs in the generator, the generator relay, or their connecting cables, the breaker will trip on the reversed flow of current from the bus; simultaneously, an auxiliary contact on the breaker opens the shunt-field circuit of the faulted generator.

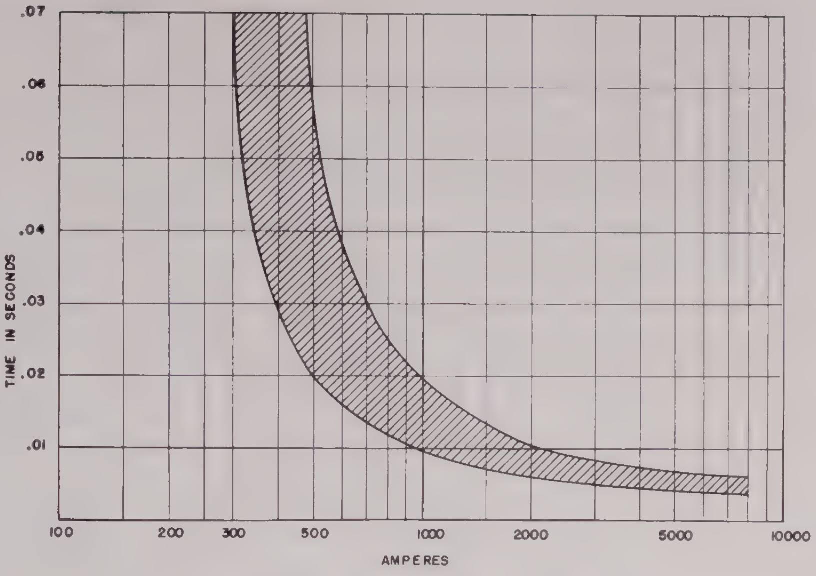

Fig. 6. Characteristics of the breaker shown in Fig. 5

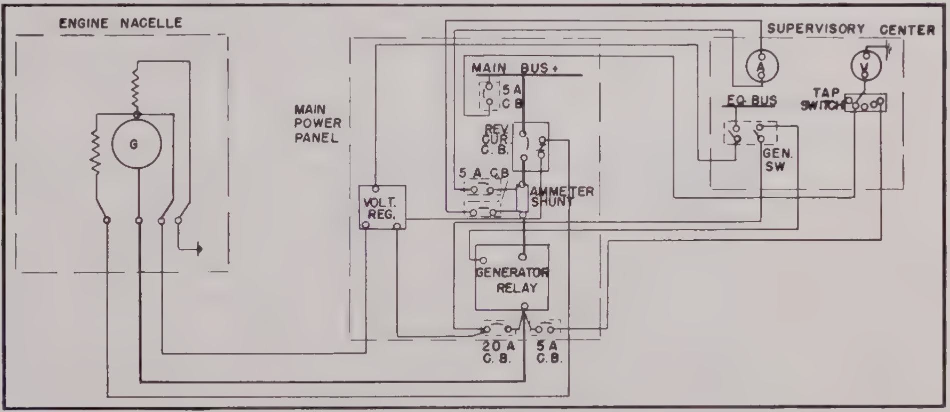

Fig. 7. Protective devices in a 30-volt d-c generator circuit

Control, Load, and Distribution Circuits

The protection of control circuits and instruments is accomplished by overcurrent circuit breakers of low rating—for example, 5 and 20 amp. These breakers are light, compact, and highly dependable in performance.

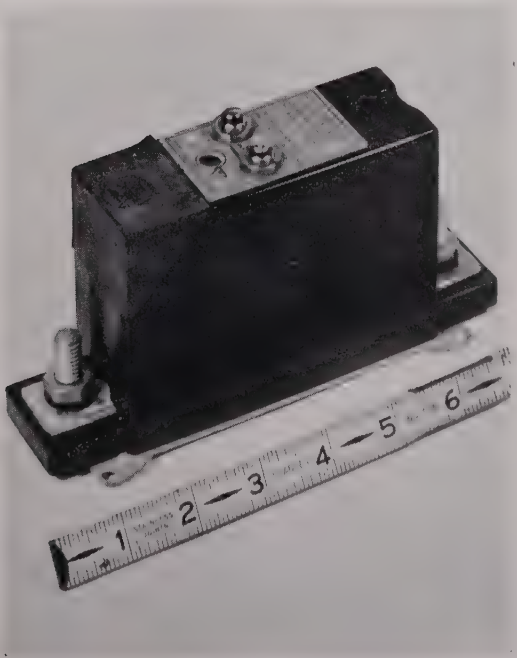

Fig. 5. Physical size and general appearance of a typical reverse-current breaker

Individual load circuits are fed from a load bus and connect directly to the utilization apparatus. A fault in one particular line would result in an excessive flow of current in that line. Therefore, overcurrent protective devices serve well in safeguarding load circuits. Most of these incorporate an inverse-time feature to compensate for initial inrush current and short-time high currents as occasioned by normal switching operations.

Distribution or feeder circuits constitute what might be termed the transmission lines of the aircraft electric system. The load buses which they feed are entirely dependent upon these channels for their supply. For that reason they require protection to the highest degree.

Feeders are in the form of single-channel and dual-channel circuits. For some applications, a single source of supply to the load bus is adequate. On all essential loads, however, power should be supplied by two or more independent feeder channels. Then, in the event of a fault, one line is still available for carrying the load. Each of the feeders in a multiple-feeder circuit should be capable of carrying continuously at least 80 per cent of the total load.

Single Channel

A fault in a single-channel feeder system would immediately produce an excessive flow of current in the line. A nondirectional overcurrent circuit breaker is sufficient to sense this high current flow and to clear the fault. It is necessary only to check the co-ordination between the breaker in the feeder circuit and those in the lines fed from the load bus. The feeder circuit breaker must have the shorter time delay in operation.

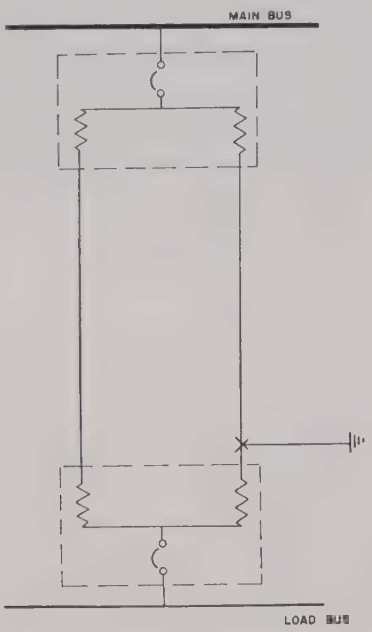

Fig. 8. Arrangement for the balanced-current system

Multiple Channel

Figs. 8 and **9** illustrate two suggested methods of supplying the load bus by a multiple-channel feed. They are a balanced-current and a dual-channel system, respectively.

Fig. 8 illustrates the application of a balanced-current protective device to a multiple-channel distribution system. The circuit breaker will trip when a specified ampere-turn difference is established between its coils.

Consider a fault applied as indicated in **Fig. 8**. The available current flows to the fault by two separate paths. Because of the difference in resistance in each path, the current divides unequally and in inverse proportion to the resistance. Thus, there is a current difference between each coil of the breaker. When this difference of current reaches a predetermined value, the protectors at both ends of the circuit will trip.

A circuit breaker has been suggested on which the coils would be interchangeable, allowing variation of the current carrying capacity and the number of turns. Then, for a particular installation with a known cable resistance, the proper coils may be selected to effect an unbalance that will exceed the minimum trip value.

The balanced-current system is not responsive to overcurrent and, therefore, no problem of co-ordination arises with the breakers in the load circuits.

Dual-channel System

The system in **Fig. 9** combines nondirectional overcurrent and reverse-current protectors. Here the trip characteristic of the reverse-current breakers is extremely fast compared to that of the overcurrent breakers. Should a fault occur at the point indicated in **Fig. 9**, the reverse-current breaker will trip on current flowing from the load bus. The thermal breaker will then trip to isolate the fault completely. The load bus will be fed by the remaining channel.

Laboratory tests have been performed to investigate the reliability of this system. In these tests were used two reverse-current circuit breakers (300 amp) and two thermal breakers (200 amp). Power was supplied by two 300-amp generators. Faults were applied to the system by connecting a length of aircraft cable from some point in the circuit, as shown in **Fig. 9**, to an aluminum alloy plate (**Fig. 2**). **Fig. 10** is an oscillogram illustrating breaker co-ordination when a fault occurs in the vicinity of the reverse-current circuit breaker.

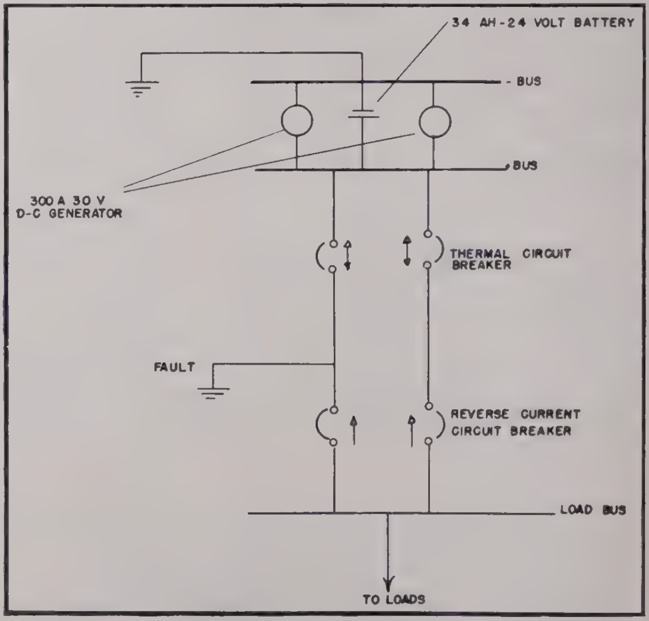

Fig. 9. Schematic diagram for the dual-channel system that combines reverse-current and overcurrent breakers

It was found that the reverse-current breaker served its purpose extremely well, faults being cleared in approximately 1.5 cycles of a 60-cycle wave.

Figs. 11 and **12** are oscillograms of faults in the vicinity of the thermal breaker. These require a slightly longer time to clear, but even this time is a matter of only a few cycles.

Fault-current and Trip-time Determination

Previous to the actual laboratory tests, a series of calculations was made to determine the fault currents and tripping times of both breakers. The values of fault resistances normally encountered were obtained from an earlier investigation.[(2)] They ranged from a minimum of 0.0001028 ohm to a maximum of 0.000975 ohm.

Faults of varying resistance in the vicinity of the thermal breaker were considered first. For each selected value of fault resistance, the total circuit resistance was computed and the system voltage determined. When a plot of voltage as a function of current for various values of total circuit resistance was imposed upon the external transient and steady-state characteristic curves of the generator, a value was obtained for the transient and steady-state fault currents encountered at those resistances. **Fig. 13** illustrates this procedure for a two-generator system. With the current values obtained and a knowledge of the time required to reach steady-state (usually 2/3 value in 0.05 sec and full steady-state value in 0.1 sec(1)) a plot was made of fault current against time (**Fig. 14**). The trip time of the reverse-current breaker could be determined from this curve.

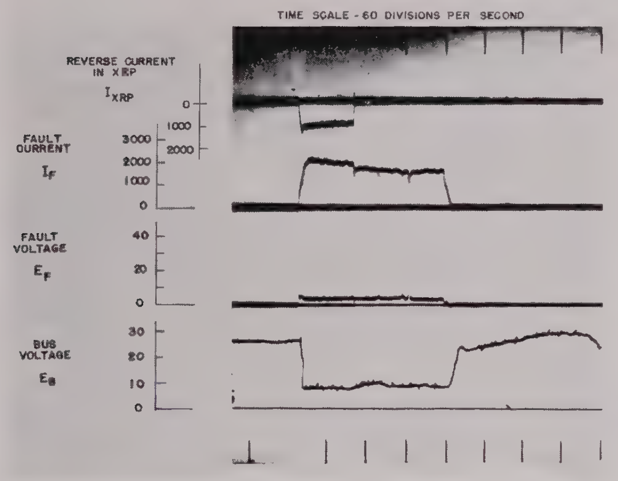

Fig. 10. Oscillogram illustrating breaker co-ordination, for the system in Fig. 9, when a fault occurs in the vicinity of the reverse-current breaker

The time of trip depends upon the flux growth in the trip coil, which builds up more slowly than the current through the breaker, approximately in accordance with the exponential relationship

$$i = i_0(1 - \epsilon^{-t/t'})$$

over the greater part of the operating range. Here i is the breaker minimum trip current, i_0 a given value of current which causes the breaker to operate in time t, having a time constant of t'.

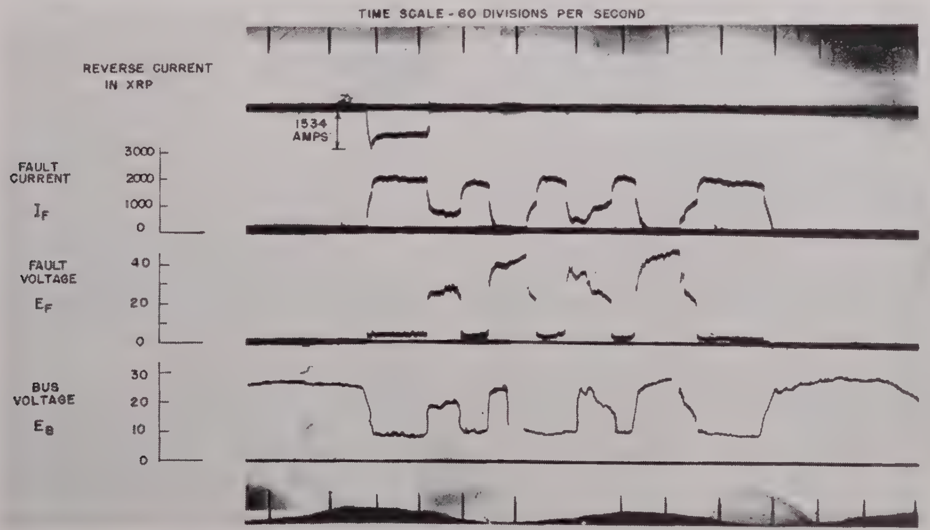

Fig. 11. Oscillogram showing the rapid clearing of an arcing fault in the dual-channel feeder when faults occur in the vicinity of the thermal breaker

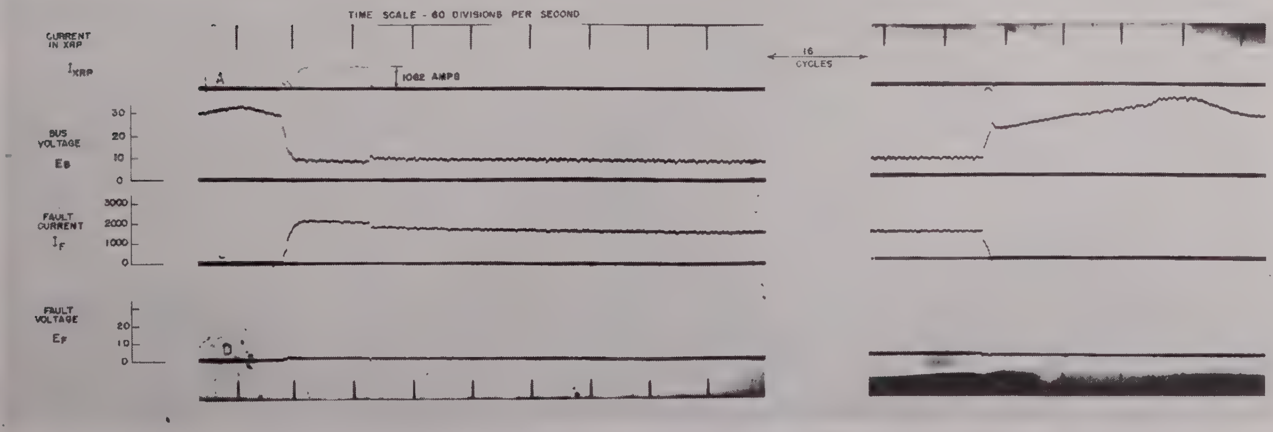

Fig. 12. Oscillogram showing the clearing of a welded fault in the vicinity of the thermal breaker

TABLE I

COMPARISON OF CALCULATED AND MEASURED VALUES OF TRIP TIME

Test No.	REVERSE-CURRENT BREAKER			THERMAL BREAKER			Type of Breaker at Fault Location
	I (Amperes)	Trip Time (Seconds)		I (Amperes)	Trip Time (Seconds)		
		Measured	Calculated		Measured	Calculated	
3–1	730	0.04	0.039	—	No trip	—	Reverse-current
3–2	650	0.045	0.046	—	No trip	—	Thermal
3–3	250	No trip	—	—	No trip	—	Thermal
3–4	700	0.04	0.042	—	No trip	—	Reverse-current
3–5	1300	0.0167	0.0155	1300	0.64	0.63	Thermal
3–9	1000	0.023	0.021	1600	0.39	0.40	Thermal
3-10	900	0.022	0.022	1400	0.52	0.50	Reverse-current
3–11	1100	0.018	0.0175		Not used		Reverse-current

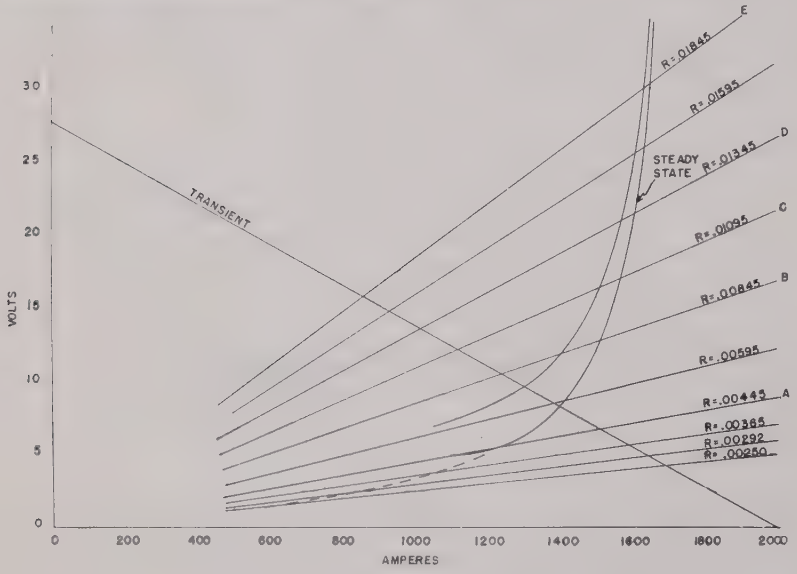

Fig. 13. Transient and steady-state curves of a two-generator system and the voltage-current curves at various fault-resistance values; the intersection of these curves yields the transient and steady-state fault currents

For a given i_0, the time to trip was determined graphically as shown in **Fig. 15**. Taking small increments of t and projecting the average current value back to a new axis at a distance from the origin equal to the time constant t' (same scale as t) yields the curve proportional to the flux build-up and, consequently, the time to attain minimum trip current. Trip times were determined using several fault resistances. From these a plot was made of current vs. trip time for the breaker as used in the circuit.

The calculations included combinations of two, three, and six generators and a cable run varying between 2 ft and 100 ft. Table I illustrates the agreement between calculated and measured values, thereby proving the reliability of a method for investigating selectivity, allowable cable lengths, trip times, and fault currents without the necessity of expensive testing.

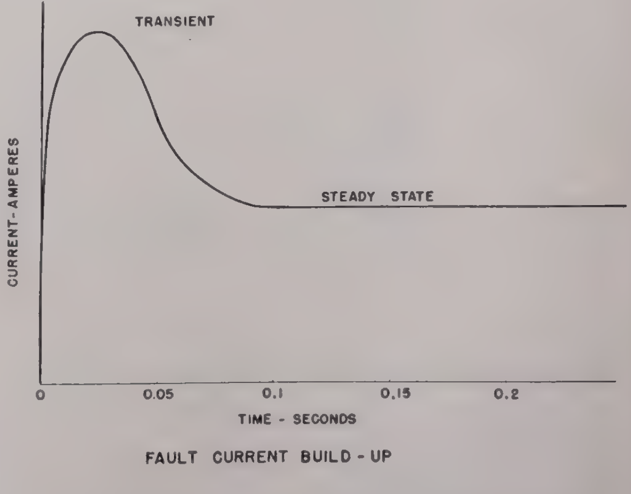

Fig. 14. Fault current vs. time, plotted with values obtained from Fig. 13

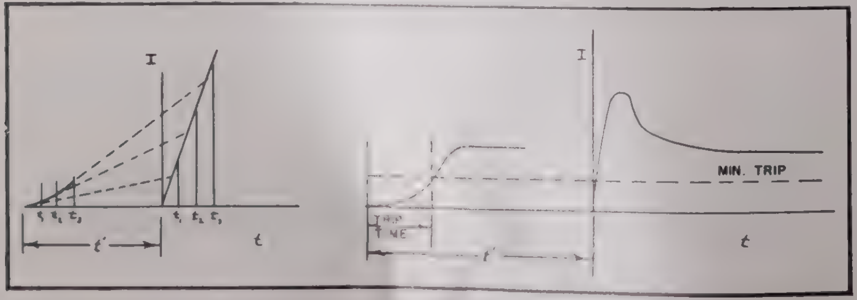

Fig. 15. Graphical determination of reverse-current-breaker trip time

SECONDARY EMISSION . . Part I

The phenomenon of the emission of secondary electrons, factors influencing yield and distribution, and some ingenious means of measuring them

By Dr. L. R. KOLLER
Research Laboratory, General Electric Company

L. R. Koller

ELECTRONS can be freed from matter in several different ways. Heating, which results in thermionic emission, is the most familiar; but electron emission is also caused by: radiation; intense fields; or bombardment by positive ions, metastable atoms or other electrons. Secondary emission is due to the last mentioned, namely, bombardment of the surface by electrons. Although secondary emission is not so familiar a phenomenon to most engineers as thermionic emission, it plays a vital part in many electronic devices.

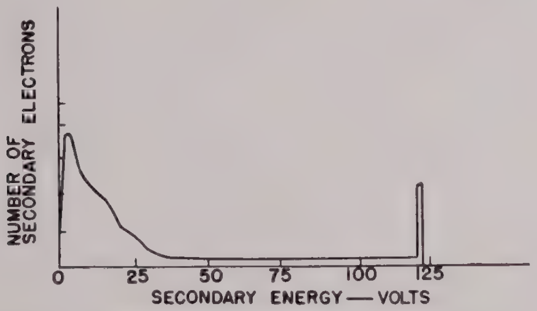

Fig. 1. Energy distribution of secondary electrons from molybdenum. Primary energy, 123 volts
(Haworth, *Phys. Rev. 48*, 88, 1935)

Secondary emission is responsible for the functioning of cathode-ray tubes, television-image tubes, television-camera tubes, secondary-emission multipliers, dynatrons, and, to some extent at least, magnetrons. It is also a disturbing feature in the performance of many receiving and transmitting tubes. The effect was discovered by Austin and Stark(1) in 1902. Since then, a considerable body of empirical information has been collected. The theoretical interpretation, however, is still incomplete.(2)(3)

Consider a metal surface towards which a stream of electrons is directed. These are called primary electrons. Some of these primary electrons may be absorbed by the metal, some may be reflected, and some may react with the electrons in the metal in such a manner as to cause them to be ejected from the surface. Any electrons which leave the surface regardless of their origin in the metal are called secondary electrons. If the stream of secondaries were examined in detail, it would be found that a small group of them have the same energy as the original primaries and hence are actually reflected primaries. There are others with somewhat less energy than the primary electrons which are probably reflected primaries that have lost some energy in the reflection process. But by far the largest proportion of the emitted electrons is a relatively low-velocity group having velocities* of about 5 to 10 volts. Strictly speaking, these are the true secondary electrons.

Fig. 1 shows the energy distribution of secondary electrons from molybdenum. The abscissas represent energy in volts, and the ordinates represent the number of electrons having energies between V and dV. The sharp peak corresponds to the reflected primaries, while the broader peak represents the true secondaries.

In practice the concern is more with the total number of secondaries emitted per primary rather than with their energy distribution. The relation between the number of secondaries per primary or the secondary-to-primary ratio (usually designated in the literature as S/P or δ) as a function of the energy of the incident primaries has a typical characteristic form which is similar for all substances. A representative curve is shown in **Fig. 2**. The ratio increases rapidly from 0 at 0 primary energy, passes through a rather flat maximum, and then falls slowly. Values for various substances will be given later in this article.

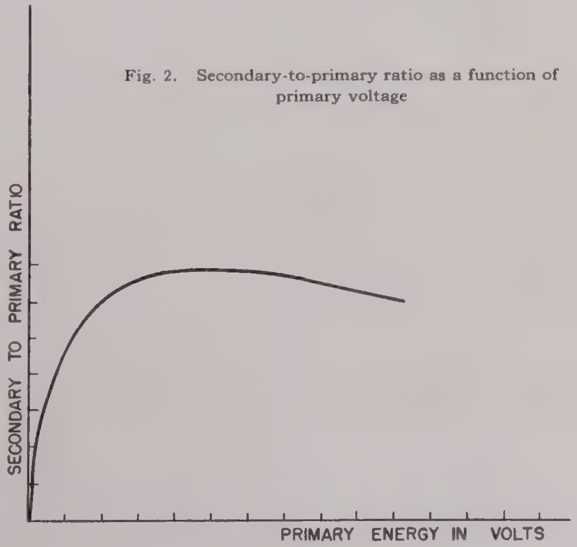

Fig. 2. Secondary-to-primary ratio as a function of primary voltage

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(1) Austin and Stark, *Ann. Phys. 9*, 271, 1902
(2) H. Frohlich, *Ann. Phys. 13*, 229, 1932
(3) D. E. Woodridge, *Phys. Rev. 56*, 562, 1939

This article is so paged that, without mutilating other articles, it can be conveniently removed for separate filing by tearing out pages 33 to 40.—Ed.

*It is customary to describe the velocity of electrons in terms of the retarding voltage against which they are just able to travel. This really is a measure of their energy rather than their velocity. An electron which would just be brought to rest in traveling against an opposing field of 1 volt is said to have a velocity of 1 volt.

The characteristic of secondary emission which makes it of practical importance is the fact that the number of secondary electrons may exceed the number of primaries incident on the surface; that is, the maximum ordinate of the curve of **Fig. 2** may be greater than 1. This makes it possible, for instance, to use secondary emission for amplification of small currents, as will be explained later.

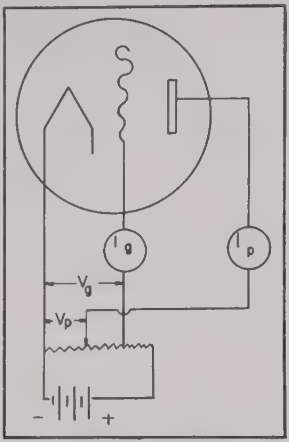

Fig. 3. Circuit for measuring secondary emission in triodes

Secondary-emission Measurements in Triodes

Secondary emission can be demonstrated qualitatively in any high-vacuum three-electrode tube. The circuit used is shown in **Fig. 3**. The grid is kept at a constant high potential V_g, while the plate voltage is varied. As the plate voltage is increased, the plate current increases, passes through a maximum, falls slowly to 0, reverses, passes through a minimum, and again reverses as is shown by curve *b* in **Fig. 4**. This behavior can be explained with the help of the yield curve *a*. The initial increase simply represents the normal rapid increase in plate current with plate voltage as determined by space-charge conditions in the tube.

As the plate voltage increases, however, the energy with which the primaries strike the plate is increased. The number of secondaries emitted per primary increases with the bombarding energy. Thus, the greater the bombarding energy (in other words, the higher the plate voltage) the more secondaries will be emitted per primary. This current of secondary electrons *from* the plate is equivalent to a decrease in the electron current *to* the plate, which accounts for the falling plate-current characteristic. This portion of the curve corresponds to voltages in the region between 0 and V_1 on curve *a* in **Fig. 4**.

As the voltage is increased still further, the number of secondaries per primary reaches the value unity, which corresponds to V_1. At this point the number of electrons arriving at the plate and the number leaving are equal; hence the net plate current is 0 and the curve reaches the axis. With further increase in voltage, the number of secondaries per primary becomes greater than 1; hence more electrons leave the plate than arrive, and the net current is an electron current *away from* the plate. Accordingly, the curve falls below the axis. This corresponds to the portion V_1 V_2 of the yield curve *a*.

As the voltage is increased still further, the plate potential exceeds that of the grid at V_g so that secondaries are repelled by the grid and no longer are able to leave the plate. Thus, the current to the plate is once more composed only of the primary electrons which reach it.

For an anode which is not as good a secondary emitter as the one graphed in **Fig. 4** and for which δ is less than 1, the curve has a similar shape but never crosses the axis. This type of curve is shown in **Fig. 5**.

The analogous behavior that is shown by tetrodes and pentodes will be described later in this article.

When the plate potential of a triode is made 0, the entire filament emission goes to the grid. If a horizontal line is drawn through this value of grid current, then the grid-current plate-voltage characteristic with respect to this line is a mirror image of the plate-current plate-voltage characteristic about the x-axis such as is shown in **Fig. 6**. This is a result of the fact that any secondary emission which is subtracted from the plate current is collected by the grid and hence must be added to the grid current.

Although secondary emission can be readily demonstrated qualitatively in triodes, these tubes are not suitable for quantitative determinations of yield. The only quantity which can be determined accurately is the voltage at which the yield equals unity. This is the voltage at which the plate-current plate-voltage curve crosses the axis. The yield itself cannot be determined accurately because it is not possible to tell how many primary electrons reach the plate and how many are intercepted by the grid on their way from the cathode to the anode.

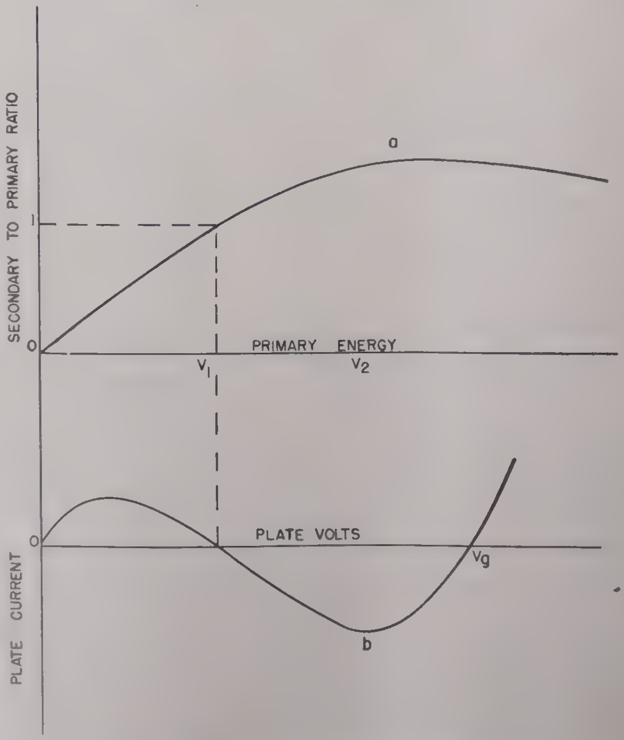

Fig. 4. Secondary emission in triodes

(*a*). Yield curve

(*b*). Triode plate-current plate-voltage characteristic

Readings of plate current give only the primary plate current minus the secondary current; whereas readings of grid current give the primary current intercepted by the grid plus the secondary current from the plate, and there is no way of distinguishing between these quantities. Thus there are two equations and three unknowns. An approximation is made by measuring the plate and grid current at very low voltages, say less than 10 volts, and assuming that under these conditions there is no secondary emission and that the same ratio of currents will hold at higher voltages.(4) These assumptions however are not strictly justified. Another approximation is made by calculating the relative currents to grid and plate on the basis of geometrical considerations. Several other ingenious methods have been suggested.(5)

Measurements of Yield in Electron-gun-type Tubes

The most satisfactory method of measuring secondary yield is to use a system in which the primary and secondary currents can be measured independently. A tube and circuit for this purpose are shown schematically in **Fig. 7**. An electron gun directs a beam of electrons through a hole in a collector onto the surface of the target under investigation. The meter i_p measures the total primary current. The current to the collector c includes all the secondaries from the target. With a well-designed tube the only electrons which can reach the collector are secondaries from the target, so that there is no ambiguity about either primary or secondary currents. An additional diaphragm can be placed between the anode and the collector to prevent stray electrons from the anode from reaching the collector. The target collector system can be made a few volts negative to this diaphragm so that if the beam is poorly focussed, secondaries from the edge of this diaphragm will not be able to reach the collector.

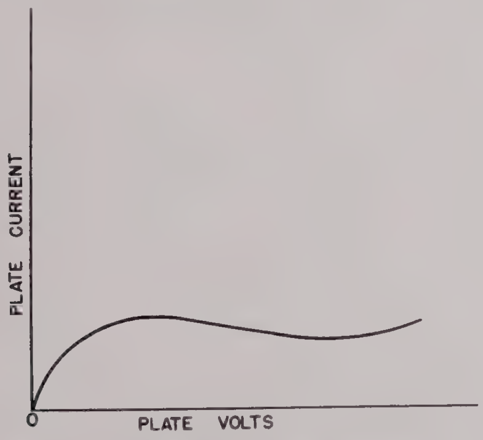

Fig. 5. Plate-current plate-voltage characteristic for secondary-to-primary ratio less than 1

Energy Distribution

The energy distribution of secondary electrons is studied by applying a retarding voltage to the collector and measuring the collector current as a function of this retarding voltage. The current corresponding to any given voltage is a measure of the number of electrons which have energy in excess of that voltage, and thus are able to reach the collector in spite of the opposing field. **Fig. 8(a)** shows a plot of collector current vs. collector voltage. At large negative voltages no current reaches the collector. As the collector is made less negative, a few high-velocity electrons reach it as indicated at V_1. As it is made still less negative, more and more electrons are able to reach it until at 0 volts it collects all emitted secondaries. There is no further change in current as the collector is made positive. The bend in the curve (saturation) does not necessarily come exactly at 0 because of differences in contact potential between the target and the collector and the space charge of the secondary electrons.

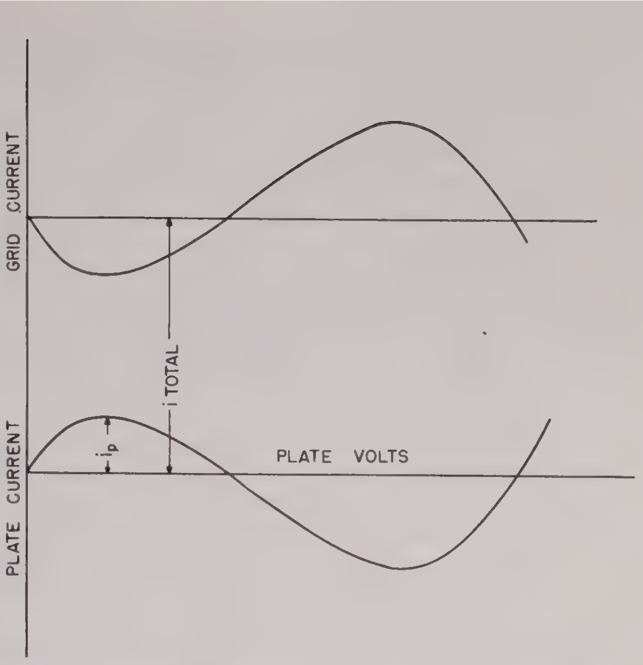

Fig. 6. Comparison of grid-current and plate-current characteristics

The ordinates of this curve give the current and hence the number of electrons having energy in excess of any given value V. To obtain a curve of the distribution in energies, it is necessary to plot the slope of this curve as a

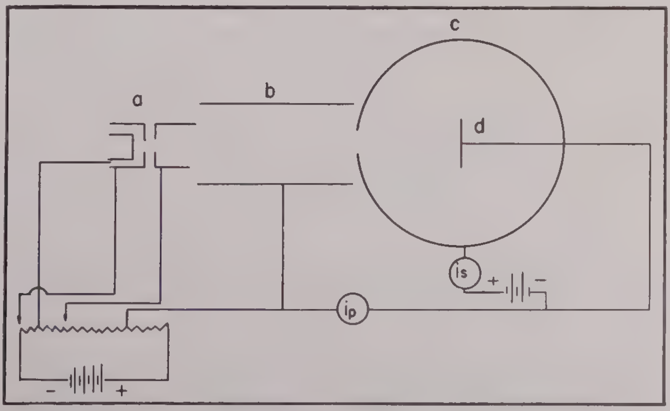

Fig. 7. Tube and circuit for secondary-emission measurements
(a). Electron gun
(b). Anode
(c). Collector
(d). Target

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(4)F. Tank, *Jb. drathl. Telegr.* *20*, 82, 1922
(5)H. Bruining: *Sckundar-Elektronen-Emission fester Korper*, Springer, 1942

function of retarding voltage as in **Fig. 8(b)**. This curve then gives the energy distribution; the ordinates give the number of electrons having energies falling between V and $V + \Delta V$. The narrow peak at the left corresponds to the high-velocity reflected primaries, whereas the broader peak at the right corresponds to the true secondaries. There is a continuous distribution in energies between these two extremes. The energy distribution depends on the material under investigation, its temperature, the primary velocity, and the angle of incidence.

Energy distribution has also been studied by magnetic deflection methods.(5)

Surface Contamination

Since electron beams in the velocity range of a few thousand volts penetrate matter to a depth of only a fraction of a micron, it is very important to have clean surfaces when making measurements. This is accomplished in various ways, depending on the material in question. It is rarely possible to clean a surface before putting it in a tube, and have it stay clean while the tube is being exhausted. The reason for this is that exposure to air usually results in the formation of an oxide film; for example, aluminum forms an oxide film when exposed to air at room temperature. This oxide is a highly refractory substance and cannot be driven off at temperatures below the melting point of aluminum. For most metals the only way to form a clean surface is by evaporating the metal onto a suitable base ***in vacuo***. If the metal is one whose oxide is easily dissociated, such as platinum, or one whose oxide is volatile at a temperature well below the melting point of the metal, like molybdenum or tungsten, the surface can be cleaned ***in vacuo*** by high-frequency induction heating. Some others, such as zirconium and titanium, have oxides which are soluble in the metal so that relatively clean surfaces can be obtained by induction heating.

Surface contamination is responsible for many of the discrepancies in the results obtained by different observers. The differences in yield between the same material treated in different ways are often greater than the differences between entirely different materials.

One of the many sources of contamination of the surface is the hot cathode used as a source of primary electrons for the electron gun. This is particularly true if an oxide-coated cathode is used, because appreciable quantities of barium and strontium are evaporated from these cathodes and in a relatively short time they may form a coating on the target that is thick enough to alter its secondary emission. This is avoided by substituting a tungsten cathode in the electron gun.

Getter is another source of contamination and, if used, must be in a side tube or so arranged that it does not deposit on the target surface.

Secondary Yield of Elementary Substances

Measurements of yield have been made on a wide variety of substances including most of the metallic and semiconductor elements, many alloys, compounds, and some insulators.

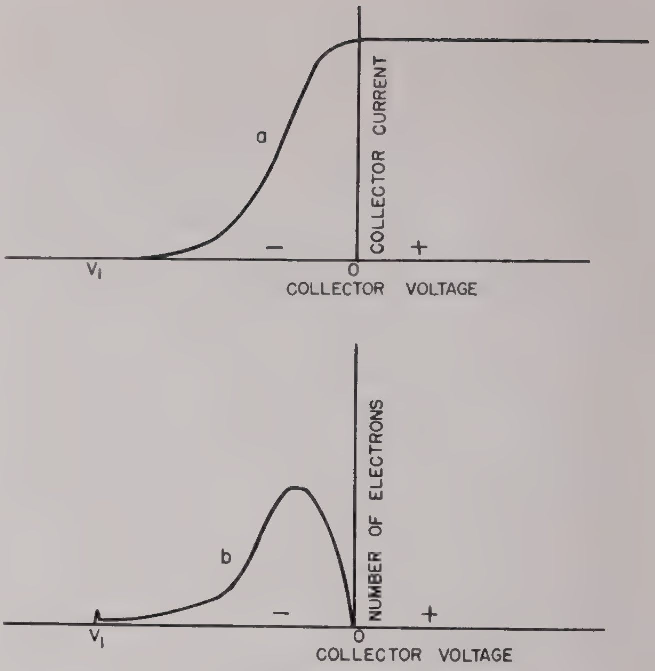

Fig. 8. Determination of energy distribution
(*a*). Collector current vs. collector voltage
(*b*). Energy distribution

In general, the yield curves for clean metal surfaces are very similar in shape and of the form shown in **Fig. 2**. Most of the metals have peak values of secondary-to-primary ratio falling between 0.5 and 2.0 The primary voltage corresponding to the peak yield varies from about 200 to 500 volts. The curve falls below unity again in many instances at about 1000 to 2000 volts or above. The values for many of the metals are given in Table I. The second and third columns respectively give the maximum yield and the primary voltage at which it occurs. The fourth and fifth columns respectively give the first and second cross-over voltages. These are the two values of voltage at which the ordinate of the yield curve equals unity.

There is no close correlation between work function and secondary yield, largely because the secondary electrons are emitted with velocities which are high compared with thermionic and photoelectric electrons.

In general, the metals with high work functions have yield curves with maximum values of 1.5. The metals with low work functions (the more electropositive elements) have maximum values of yield falling between 0.4 and 1. Although some observers have reported higher yields for some of these metals, it seems likely that the high values are the result of measurements on contaminated surfaces.

Bruining attributes the low secondary emission from the electropositive metals to the fact that these are, for the most part, light elements into which the primary electrons penetrate deeply. Hence, the secondaries are released at considerable depths within the metal and are strongly absorbed before they reach the surface.

Most of the published data on metals have been for polycrystalline surfaces. A few measurements which have been made on single-crystal surfaces have shown that the yields differ for different crystalline faces.(6)

TABLE I

VALUES OF MAXIMUM SECONDARY YIELD AND CORRESPONDING VOLTAGE OF MANY METALS

Metal	δ max	$V_{\delta\,\max}$	V_1	V_2	Reference
Lithium	0.6	100			(1)
Potassium	0.8	300			(2)
Rubidium	0.9	300			(2)
Cesium	0.7	300			(1)
Copper	1.28	600	200	>1000	(1)
Silver	1.56	800	140	>1000	(1)
Gold	1.4	1000	175	>2000	(3)
Beryllium	0.45	300			(4)
Magnesium	0.85	300			(4)
Barium	0.8	400			(1)
Boron	1.2	150	50	550	(4)
Aluminum	0.95	300			(1)
Aquadag	0.75	350			(4)
Aquadag +bentonite	1.8	400	80	1600	(4)
Silicon	1.1	250	120	520	(4)
Germanium	1.2	400	150	1350	(4)
Titanium	0.9	250			(5)
Zirconium	1.1	350	190	>600	(5)
Thorium-coated tungsten	1.2	350	230	940	(6)
Columbium	1.2	350	150	1100	(7)
Tantalum	1.25	600	275	>1500	(4)
Chromium	1.10	400	250	900	(4)
Molybdenum	1.2	350	140	1100	(4)
Tungsten	1.45	600	200	>1600	(4)
Manganese	1.35	200	50	750	(4)
Iron	1.3	350	120	1400	(8)
Cobalt	1.35	500	120	>1500	(4)
Nickel	1.35	450	140	1650	(4)
Palladium	1.65	550	90	>1500	(4)
Platinum	1.8	700	150	>2000	(9)

(1) Bruining and de Boer, *Physica 5*, 17, 1938
(2) Afansjewa and Timofeew, *Techn. Phys. USSR 4*, 953, 1937
(3) Copeland, P. L., *Phys. Rev. 48*, 96, 1935
(4) Koller, L. R., Unpublished
(5) Bruining and de Boer, *Philips. Techn. Rdsch. 3*, 80, 1938
(6) Coomes, E. A., *Phys. Rev. 55*, 519, 1939
(7) Warnecke, R., *J. Phys. Radium 7*, 270, 1936
(8) Petry, R. L., *Phys. Rev. 26*, 346, 1925
(9) Copeland, P. L., *Phys. Rev. 40*, 122, 1932

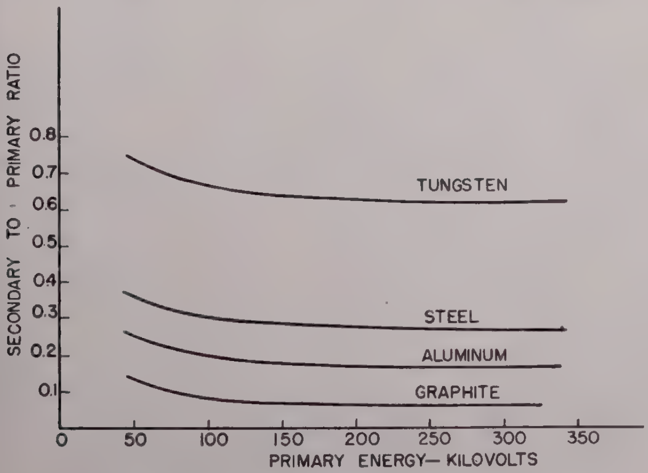

Fig. 9. Secondary emission produced by high-voltage primaries

The yield also depends to some extent on the smoothness of the surface. Comparisons of measurements on smooth and rough surfaces, such as soot and carbon and black and polished nickel, indicate that the yield is higher for smooth than for rough surfaces. The reason is probably because the secondaries are trapped in the crevices between the particles of rough surfaces.(5)

Measurements made at the melting point, Curie point, and transition points show relatively small changes in secondary emission.(5) Different observers are not in good agreement and additional data are needed.

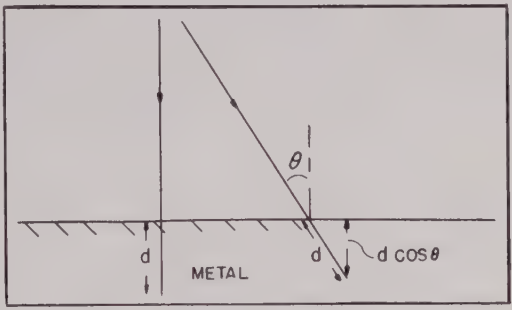

Fig. 10. Effect of oblique incidence

Numerous measurements have been made on the effect of temperature on secondary emission. No significant effect has been found for pure metals. This is reasonable to expect, since the energy of secondary electrons is large compared with the thermal excitation energy of electrons. However, for oxide-coated cathodes a large increase in yield with increasing temperature has been observed. Pomerantz(6) finds that the difference between the yield at temperature T deg K and the yield at room temperature can be expressed by the equation

$$\Delta\delta = A\epsilon^{-Q/2kT}$$

where

A = Constant
Q = Activation Energy
k = Boltzmann constant
T = Absolute temperature, deg K

When this is extrapolated to oxide-coated cathode operating temperature of 1123 K, values exceeding 100 are obtained.

Very few measurements have been made on the yields produced by primaries at velocities greater than 20 kv. Some measurements on carbon, aluminum, iron, and tungsten at voltages up to 340 kv made by Trump and van de Graf(7) are shown in **Fig. 9**.

Effect of Angle of Incidence

Generally for smooth surfaces, the secondary yield increases with increasing angle of incidence. This is to be expected because at oblique angles of incidence the secondaries will be released closer to the surface than for normal incidence. For example, in **Fig. 10** assume that a normally incident primary electron is stopped by the time it has penetrated a distance d below the surface. If the electron is incident at an angle θ, after traversing the same distance d through the metal, it will be only at a distance $d \cos\theta$ below the surface. Accordingly, the secondaries being emitted closer to the surface will suffer less absorption. **Fig. 11** shows the variation in secondary yield with angle of incidence observed by Muller(8) for a number of metals. The increase between 0 and 90 deg is threefold in some instances. Although this explanation is in good qualitative agreement with the facts, it has not been possible to derive a satisfactory quantitative relation.

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(6) M. A. Pomerantz, *Jour. Franklin Inst. 241*, 415, 1946
(7) Trump and van de Graf, *Jour. App. Phys. 18*, 327, 1947

Rough surfaces show very little variation with angle of incidence because the angle of incidence is not clearly defined. Also, at low primary velocities the effect is small because of the slight depth of penetration of the primaries.

Semiconductors

The semiconductors such as Si, Ge, and B have yield curves which can hardly be distinguished from the metals. These elements are included in Table I.

Compounds

The formation of a thin layer of a compound on the surface of a metal produces striking changes in its secondary emission. In nearly all instances reported to date, the formation of a surface layer of a compound of the electropositive metals leads to a marked increase in secondary yield. For example, clean Mg has a yield of less than 1, while a thin film of MgO (approximately 1000Å) has a yield of 10. Similarly, clean Be has a yield of 0.4, whereas a thin layer of oxide on a beryllium surface has a yield of 8. Cesium has a yield of less than 1 but the composite silver-cesium oxide films used in photo cathodes may have yields as great as 10. Similar effects have been observed for halogen compounds. Values for a few compounds of electropositive metals are given in Table II.

On the other hand, compounds of metals with high values of work function give yields in the neighborhood of 1. A few of these are given in Table III.

Alloys

One convenient way of forming oxide surfaces is by the use of alloys. In some instances, an alloy of silver and magnesium is used.(9) When this is heated in a low pressure of oxygen, the magnesium diffuses to the surface where it oxidizes, forming a thin layer of MgO of readily controllable thickness. This material has the advantage of having the mechanical properties of silver, together with a reduction of the vapor pressure of the magnesium. An alloy of copper and beryllium has been used in an analogous manner.

The Secondary Emission from Insulators

The measurement of the secondary emission from insulators presents some difficulties. Regardless of the emitting properties of the surface in the *steady state*, the secondary emission from a perfect insulator is always either zero or unity. This is not really a property of the surface but a consequence of the lack of conduction through the material. This can best be explained by considering a metal electrode completely insulated from its surroundings. Thus, suppose a beam of electrons to be incident on a metal target which is mounted on insulating supports. Assume that the target is made of clean nickel which normally has a yield curve a as shown in **Fig. 12**. If the beam voltage is at any value below the point V_1 on the yield curve where $\delta = 1$, the target will charge up to, and remain at, cathode potential.

TABLE II

VALUES OF YIELD FOR COMPOUNDS OF ELECTROPOSITIVE METALS

Compound	δ max	Reference
MgO	11	(1)
BeO	8	(1)
BaO	4.8	(2)
Al_2O_3	3	(2)
LiF	5.6	(3)
NaF	5.7	(3)
CaF_2	3.15	(3)
BaF_2	4.5	(3)
NaCl	6.8	(3)
KCl	7.5	(3)
RbCl	5.8	(3)
CsCl	6.5	(3)
NaBr	6.25	(3)
NaI	5.5	(3)
KI	5.6	(3)
Cs-CsO-Ag	10	(4)

(1)L. R. Koller, unpublished
(2)Bruining, *Physica 5*, 17, 1938
(3)Bruining, *Physica 6*, 834, 1939
(4)Zworykin and Morton: *Television*, Wiley, 1940

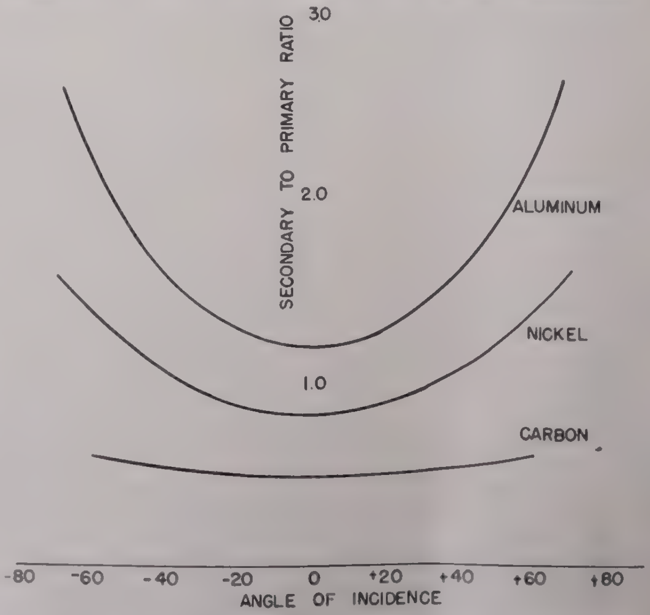

Fig. 11. Variation in secondary yield with angle of incidence of primary beam

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(8)H. O. Muller, *Zeit. Phys. 104*, 475, 1937
(9)Zworykin, Ruedy, and Pike, *Journ. App. Phys. 12*, 696, 1941

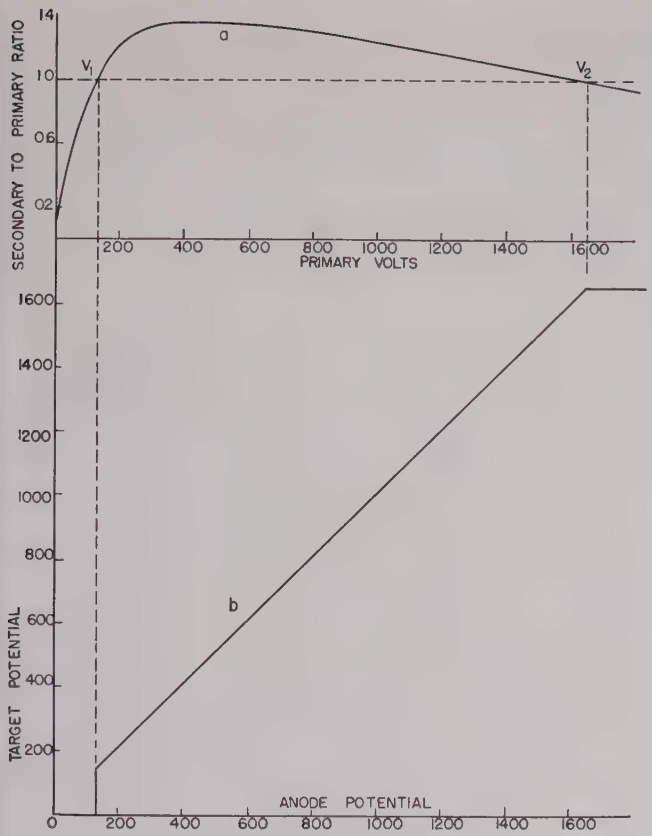

Fig. 12. Potential of insulated electrodes
(*a*). Secondary yield from nickel
(*b*). Target potential as a function of anode potential

The reason for this is that each electron which reaches the surface causes the emission of less than 1 secondary so that each arriving electron results in the acquisition of negative charge by the target, because the only way for the insulated target to discharge is by secondary emission. This process continues until the target accumulates enough charge to bring it to cathode potential, when no further electrons can reach it.

If the beam velocity is between V_1 and V_2, a different situation exists. Each incident electron now causes the emission of more than one secondary; that is, for each arriving electron the plate emits more than one electron or, in other words, each arriving electron makes the plate more positive. Thus, as soon as V_1 is exceeded, the plate charges up abruptly and tends to approach the anode potential. It can never quite reach it because as soon as the plate approaches anode potential there is no accelerating field to draw the secondaries from the plate. The secondary emission decreases, and the plate becomes more negative until the field between it and the cathode is just sufficient to maintain it at a potential where it loses 1 secondary for each primary which strikes it.

If the plate potential is slightly increased above this stable equilibrium value, the secondary emission decreases. The plate then becomes more negative and returns to its equilibrium potential. On the other hand, if the plate is slightly displaced towards negative potentials, the field between it and the anode is increased so that more secondaries can leave it. Thus, the plate becomes more positive and returns to equilibrium. Hence, in the range of potentials between V_1 and V_2, an insulated metal electrode tends to maintain itself at a potential somewhat below that of the anode. The exact value depends on the space-charge conditions in the tube. (This applies only to surfaces which have the property of being able to emit more than 1 secondary per primary.)

Insulated surfaces with yields less than 1 in well-evacuated tubes will remain at cathode potential. If the beam voltage (that is, the anode voltage) exceeds V_2, the second crossover voltage, the target potential remains constant at V_2. Any increase in target potential would result in a decrease in secondary yield and an accumulation of negative charge which would restore the target towards V_2. A decrease in target potential would increase the secondary yield, making the target more positive and also restoring it to the point of stable equilibrium. Consequently, as the anode potential is raised, the target potential also increases up to V_2 where it stays or sticks, causing it to be known as the "sticking" potential. This characteristic presents a fundamental limitation in some cathode-ray tubes.

The relation between the yield curve and the potential assumed by the surface of an insulated electrode is shown in **Fig. 12**. As the potential is increased from 0, the surface remains at 0 or cathode potential until the voltage reaches V_1, corresponding to a yield of 1 secondary per primary. At this point the surface abruptly rises to nearly anode potential. As the anode potential is increased, the surface stays practically at anode potential until V_2 is reached. This is the sticking potential. As the anode is raised beyond V_2, the potential of the surface remains constant at V_2(10)

TABLE *III*(5)

THE YIELDS OF COMPOUNDS OF METALS WITH HIGH VALUES OF WORK FUNCTIONS

Compound	δ max
MoS_2	∽1.10
MoO_2	1.09–1.33
WS_2	0.96–1.04
Cu_2O	1.19–1.25
Ag_2O	0.90–1.18

The surface of an insulator is a case quite similar to that of an insulated electrode. Measurements on a few insulators have been made by rather complex methods, and some of the results are given in Table IV. For imperfect insulators—that is, high resistances—the conditions are slightly different. In the cases that have just been considered, the target surface can gain or lose charge only by primary and secondary emission. If, however, the target is connected to the anode through a high-resistance path, it can gain or lose charge through this path and, as a consequence of the *iR* drop, its potential will be slightly altered.

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(10) Hagen and Bey, *Zeit. f. Phys. 104*, 681, 1937

Cathode-ray Tubes

The emission from insulators is a matter of considerable importance in all forms of cathode-ray tubes. In these tubes, the fluorescent screen on the end of the bulb is poorly conducting and hence is practically insulated from the anode coating on the wall of the bulb.

TABLE IV*

RESULTS OF MEASUREMENTS ON SOME INSULATORS

Insulator	δ_{max}	$V_{\delta\,max}$	V_1	V_2
Mica	2.5	380	30	3500
Quartz	2.9	440	<50	3800
Cover glass	1.9	330	<60	1700
Hard glass	2.3	340	<40	2300

*H. Salow, *Zeitshrift fur Technische Physik* 21, 8, 1940.

If its secondary yield were less than 1, it would charge up to cathode potential and remain there, rendering the tube useless. Since the emission from the phosphor surfaces used is greater than 1, they tend to follow the anode potential in the range V_1 to V_2 as shown in **Fig. 12**, by emitting secondaries to the tube wall. If, however, the anode potential exceeds V_2 the screen surface sticks at V_2 and, although the anode voltage is raised, the screen voltage can never exceed V_2. Since the energy of the incident electrons is limited to V_2 regardless of the anode voltage, the screen brightness remains constant.

This sticking potential for some phosphors is of the order of 5000 to 10,000 volts and imposes a fundamental limitation on the brightness of the cathode spot obtainable with them. This phenomenon has been studied at considerable length and the effects of various binders, getters, and exhaust procedures on sticking potential investigated.(11) It is probably not of importance in tubes in which the phosphor is deposited on a conducting background or coated with a conducting metal surface as is the case with many high-voltage television tubes.

Field Effects

The secondary current from pure metal surfaces shows good saturation with increasing positive collector field. For compounds however this is not the case, and the secondary current increases to some extent with increasing collector voltage.

When insulators are present in the form of a very thin film on a conducting background, they exhibit a type of field emission first discovered by Malter.(12) This effect is best exhibited on a film of Al_2O_3 formed electrolytically on the surface of aluminum sensitized by treating in cesium and oxygen. When this type of electrode is bombarded by primary electrons of the order of 1000 volts velocity, very large secondary-to-primary ratios are observed which may be as great as 1000 to 1. These differ from ordinary secondary emission not only with respect to the high ratio but also because they show some time effects. The maximum yield is established only some tenths of a second after starting the bombardment. If the primary current is interrupted, the secondary current decays slowly over a period of minutes or even hours.

The effect is not true secondary emission but rather an effect due to the field produced through the insulator by secondary emission from its surface. The surface when bombarded behaves like any insulator having a yield of greater than 1 and tends to attain anode potential. If the conducting background is kept below anode potential, this results in a field through the insulating layer. If the thickness of the oxide layer is of the order of 1000Å, the field strength may be of the order of 10^6 volts per cm. Fields of this strength are sufficient to give field or cold-cathode emission. The field electrons which are produced in the underlying layer pass through the oxide to the collector.

Since this field depends on collector voltage, the secondary yield is also a function of collector voltage. Studies(13)(14) have shown that these field currents originate in localized spots on the surface of the target and that these currents show marked variations with time.

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(11) W. B. Nottingham, *Journ. App. Phys. 8*, 762, 1937
(12) L. M. Malter, *Phys. Rev. 50*, 48, 1936
(13) Koller and Johnson, *Phys. Rev. 52*, 519, 1937
(14) H. Mahl, *Zeit. techn. Phys. 18*, 559, 1937

(To be continued)

*new contactor

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HIGH-VOLTAGE RECTIFIER CIRCUITS . . . Part III

Operation of voltage-multiplier circuits—advantageous for high-voltage small-current applications. How they can be built up from a basic circuit and modified to produce a desired output

By E. V. De BLIEUX
Power Transformer Engineering Division
Pittsfield Works, General Electric Company

THE most commonly used voltage-multiplier circuits are shown in Table III. In circuits of this type a relatively low-voltage high-current single-phase transformer is used to supply a high-voltage low-current d-c voltage that is several times the peak voltage of the transformer d-c winding.

The voltage multiplication is accomplished by charging a main set of series-connected capacitors from an auxiliary set, also series-connected. The auxiliary set is connected to the transformer d-c winding and to the rectifier tubes in such a manner as to operate as swinging capacitors. The set is charged from the d-c winding at the low end of the voltage swing and discharge into the main set of capacitors at the high end of the swing.

It is advisable in circuits of this type to use current-limiting resistors to limit the capacitor charging current where the rectifier tubes have emission-limiting characteristics. Otherwise, overheating of the rectifier-tube anode may occur.

Voltage-multiplier circuits are sometimes called ladder circuits because of the similarity of the circuit diagram to a ladder and because each section added is like another rung added, enabling the voltage to climb higher.

Although these circuits are commonly called voltage-multiplier circuits, the output voltage is actually only an approximate multiple of the d-c winding peak voltage and, under some conditions, the multiplier may be less than one.

The degree of multiplication obtained is a function of the tube arc drop and the ratio of the capacitance of the capacitor to the load current. A more descriptive name for this class of circuits might be "voltage-additive circuits."

The voltage-multiplier circuits shown in Table III each include a rectifier transformer, although the rectifier transformer may be omitted if a supply voltage of the proper value is available. If the transformer is omitted, the location of the ground point—and, in fact, whether there can be a ground point—depends on whether the supply circuit is, or can be, grounded.

For Circuits *1*, *2*, and *3* (Table III), the rms voltage of the d-c winding is equal to 0.354 times the no-load d-c voltage; and the peak i[illegible] is twice the peak voltage of the d-c winding

For Circuits *4*, *5*, and *6*, the rms voltage of the d-c winding is equal to the no-load d-c voltage divided by the number of stages in the multiplier circuit; and the peak inverse voltage is twice the peak voltage of the d-c winding.

Factors for determining the current rating that is required for the d-c winding and the tubes cannot be given because they are a function of the load, rectifier-tube voltage drop, capacitor, rectifier transformer, and other circuit characteristics.

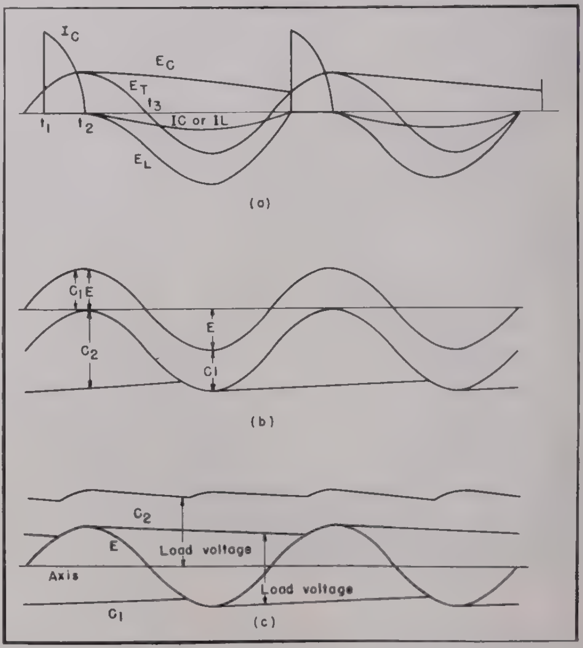

Fig. 6. Voltage and current wave shapes for voltage-multiplier circuits: (a) Circuit *1* (Table III); (b) Circuit *2*; and (c) Circuit *3*

For the consideration of the voltage-multiplier circuits, some of the principles of rectifier-tube operation to note are as follows:

(a). Current flows from anode to cathode and only while the potential of the anode is positive with respect to the cathode.

(b). Current flow is from the positive terminal of the rectifier (anode) through the load to the negative terminals (cathode).

(c). While the capacitor is being charged, the current flow *through the capacitor* is from positive plate to negative plate. During discharge of the capacitor, the

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current flow *through the capacitor* is from negative plate to positive plate.

(d). Heating the cathode increases the supply of electrons available.

Voltage-doubler Circuits

Single-way, One tube

Circuit *1* (Table III) is the simplest voltage-doubler circuit, requiring only one tube and one capacitor. With the positive terminal grounded, the filament of the tube is at ground potential. This permits the use of a simple filament transformer—or its omission, if suitable filament voltage is available.

If the negative, instead of the positive, terminal is grounded, one end of the d-c winding will be at ground potential; and a filament transformer insulated for the full voltage will be required. For this reason, it is usually preferable to ground the positive terminal.

This circuit has the same elements as the half-wave single-way Circuit *1* (Table I*) with the exception that a capacitor has been added and the rectifier tube is in parallel instead of in series with the load circuit.

Referring to **Fig. 6(a)**, the operation of this circuit is as follows:

During the interval t_1 to t_2 of the positive half-cycle of the transformer voltage, the tube conducts, and the transformer charges the capacitor. While the tube is conducting, the load voltage E_L is zero (zero tube voltage assumed).

At t_2, the voltage of the d-c winding passes its positive crest, the tube stops conducting, and the load voltage becomes the difference between the capacitor voltage E_C and the decreasing d-c winding voltage E_T. After the d-c winding voltage passes through t_3 (zero), it is in the same direction as the capacitor voltage, and the load voltage is the sum of the capacitor and d-c winding voltages.

However, when the load impedance is high this circuit may not be satisfactory because of the core saturation effects of the d-c current component in the d-c winding current.(e)

Single-way, Two tubes

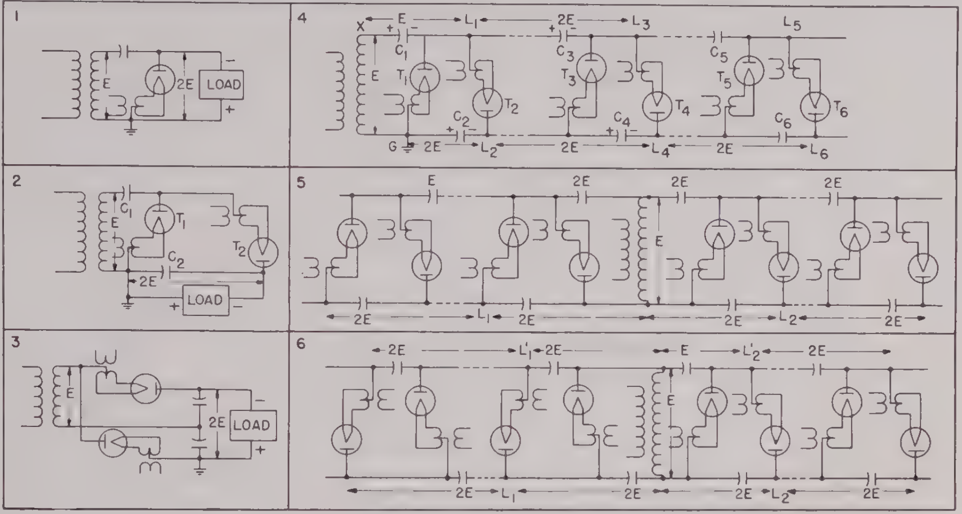
Circuit *2* (Table III) is Circuit *1* with a second tube and capacitor added.

The addition of the second tube and capacitor eliminates the interval of zero load voltage that occurs with Circuit *1*. Therefore both the load voltage and load current have a higher and more uniform amplitude than Circuit 1 provides. Circuit *2* is preferable to Circuit *1* for many applications. The voltage wave shapes are as shown in **Fig. 6(b)**.

It can be shown(5) that neither this circuit nor the voltage-doubler circuits considered later will give a multiplication greater than one unless the ratio of load resistance to tube resistance is greater than approximately 10.(f)

Table III

VOLTAGE-MULTIPLIER CIRCUITS FOR HIGH-VOLTAGE RECTIFIERS



Mechanical Analogy

A mechanical analogy that will assist in understanding the operation of Circuit *2* (Table III) and other voltage-multiplier circuits is shown in **Fig. 7**. The corresponding components of the mechanical analogy and of Circuit *2* are indicated by the same symbols.

Fig. 7 shows a wheel half immersed in water. Fastened to the wheel is a container C_1 that is always upright. As the wheel turns, the distance between the base of C_1 and the water level is equal to E. C_1 has a height equal to $E_{\max}$.

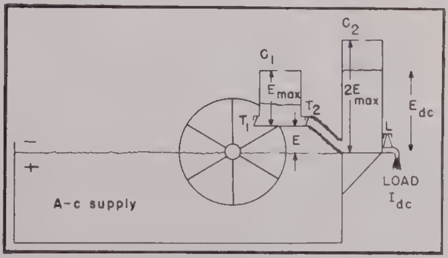


Fig. 7. Mechanical analogy for Circuit *2* (Table III)

Check valve T_1 permits water to flow into C_1 whenever the water level in C_1 is below the water level in the tank. Check valve T_2 permits water to flow from C_1 to C_2 whenever the water level in C_1 is above the water level in C_2. Water (I_{DC}) discharges continuously from C_2 if *LOAD* faucet is open.

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*Table I appeared in Part II of this article, in the March issue.

(e) Method of calculating circuit characteristics that include the effect of transformer reactance are given in: Electrical Engineering Staff of M.I.T.: *Applied Electronics*, John Wiley & Sons, Inc., New York.; "Graphical Solution of Rectifier Circuits," by Panofsky and Robinson, *Electronics*, April, 1941, p. 42.

(f) A detailed consideration of this circuit is given in: "The Half-wave Voltage-doubling Rectifier Circuit," by D. L. Waidelich and C. H. Gleason, *Proc. IRE*, Dec. 1942, p. 535.

C_1 is filled every time the wheel carries it below the surface of the water. The portion of the water in C_1 transferred to C_2 as the wheel carries C_1 above the water level depends on the resistance of T_2 (including hose) and the relative levels of water in C_1 and C_2. The amount of water that drains out of C_2 depends on the size of C_2 and the relative quantity of water flowing into and out of C_2.

If C_1 has a large volume (the height $2E_{\max}$ is fixed), the level in C_2 and the pressure E_{DC} will fluctuate less for a given rate of water discharge I_{DC} than when C_2 has a small volume.

Furthermore, if water flows slowly into C_2 (resistance of T_2 high) the maximum height of water in C_2 will not approach $2E_{\max}$. If the water flows out of C_2 slowly (resistance of L high) the level in C_2 will remain near $2E_{\max}$.

This explains why in voltage-doubler circuits the ratio of load resistance L to tube resistance T_2 must be greater than approximately 10 to obtain voltage multiplication greater than one—that is, a level in C_2 higher than $E_{\max}$.

If C_2 is omitted and faucet L put in the place of T_2, the mechanical analogy will apply to Circuit *1*.

Similar mechanical analogies for the other voltage multiplier circuits can be constructed.

Double-way, Two tubes

Circuit *3* (Table III) functions as two half-wave single-way rectifiers operating in series from a single d-c winding to charge, during alternate half-cycles, two capacitors so that their voltages are in series across the load circuit. This provides a load voltage that is approximately double the transformer voltage. The voltage wave shapes are as shown in **Fig. 6(c)**. Some writers call this the Greinacher or Liebenow Circuit.

Comparing this circuit with the half-wave single-way Circuit *1*, it will be noted that, for the same output voltage and current, this circuit has a higher utility factor, eliminates the d-c flux from the core, and reduces the d-c winding voltage and tube inverse voltage to one-half that of the half-wave single-way circuit.

It can be shown(5) that, depending on the circuit constants, the forward and inverse tube voltages and maximum tube current are larger and ripple voltage less than for the single-way half-wave doubler (Circuit *2*). During the portion of the cycle when the capacitor is charging, the tube current is the sum of the load and the capacitor charging currents

With one side of the load [illegible] grounded, the d-c winding must be insulated for full-load voltage at the end connected to the tubes, and for half-load voltage at the other end.

This circuit is like the diametric double-way bridge (Circuit *3*, Table I) except that in the two branches connected to one end of the d-c winding, rectifier tubes are replaced by capacitors.

Circuit *3*(g) is useful for applications where it is not economical to build a transformer for the small current and high voltage required or when the tubes will not withstand the higher inverse voltage of the single- and double-way circuits.

For the reasons given in the consideration of Circuit *2* it is preferable to ground the positive terminal.

For the same d-c winding voltage, the output voltage is higher, and the tube inverse voltage is lower, for this circuit than for Circuits *1*, *2*, and *3* (Table I).

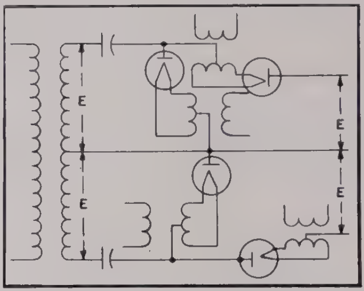

Fig. 8. Modification of the diametric full-wave single-way Circuit *2* (Table III)

For certain applications, such as cable testing, the connection between the two capacitors is brought out and connected to ground. With this arrangement, the plus and minus terminals are connected to the two conductors of a two-conductor cable, and tests of full voltage between cables and half voltage to sheath and ground are made simultaneously.

A modification of the diametric full-wave single-way Circuit *2* (Table I) that changes it to a voltage-doubler circuit for similar applications is shown in **Fig. 8**. The tubes in series with the positive and negative lines prevent leaking off of the charge on the cables during the half-cycle when each cable is not being charged.

Circuits for Multiplications Greater Than Two

All of the circuits shown in Table III that produce multiplications greater than two are based on Circuit *2*. It will be shown that odd and even multiples greater than two can be obtained with either single-way or double-way operation of the rectifier transformer.

The addition of rectifier tubes and capacitors in discrete steps produce higher and higher multiplications, but because of rectifier-tube resistance, each addition stage does not add double voltage, because in each stage the voltage is reduced by the rectifier-tube drop of the stage. Since all the rectifier tubes are effectively in series, the limit is reached when the sum of the tube-voltage drops equals that of the d-c winding voltage. If the multiplication is carried to many stages, the voltage gain after the first few stages is very slight. Thus it is evident that there is a practical limit to the amount of multiplication that is obtainable.

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(5) "Characteristics of Voltage Multiplying Rectifiers," by D. L. Waidelich and C. L. Shackelford, *Proc. IRE*, vol. 32, No. 8, Aug. 1944, p. 470.

(g) For detailed calculations of Circuit *3*, see "Characteristics of Voltage Multiplying Rectifiers," by D. L. Waidelich and C. L. Shackelford, *Proc. IRE*, vol. 32, No. 8, Aug. 1944, p. 470.

"The Diode as a Half-wave, Full-wave, and Voltage-doubling Rectifier," by N. H. Roberts, *The Wireless Engineer*, July 1936, p. 351.

"The Full-wave Voltage-doubling Rectifier Circuit," by D. L. Waidelich, *Proc. IRE*, Oct. 1941, p. 554.

To obtain reasonable efficiency, the sum of the tube drops should probably not be more than approximately 30 per cent of the rectifier-winding peak voltage. This is why multiplying circuits are suitable principally for applications requiring very small currents and high voltages.

When the required d-c voltage is of such a value that the peak inverse voltage exceeds the rating of the tubes available, one solution is to use two or more tubes in series and connect a resistance voltage divider in parallel with the cascaded tubes to maintain uniform voltage distribution between tubes. Voltage-multiplier circuits accomplish this voltage division without the use of the equalizing resistor and permit the use of a lower-voltage d-c winding on the transformer.

Single-way, Even Multiplier

Circuit *4* (Table III) shows how multiplier circuits are built from the single-way (half-wave) voltage-doubler circuit.

The portion shown to the left of the dotted connections is the same as Circuit *2* (Table III). The addition of sections consisting of one capacitor and one rectifier tube as shown to the right, with proper circuit constants, gives a multiple of approximately $2E$ for each section added.

This circuit therefore produces between the indicated ground point and the even-numbered L terminals a d-c voltage that is approximately an even multiple of the d-c winding peak voltage.

Between terminal X and the even-numbered L terminals, voltages with average values equal approximately to even multiples of the secondary-winding peak voltage exist. However, these voltages will have a ripple equal to the secondary-winding peak voltage. The voltage at these terminals will be as indicated in **Fig. 9(a)**.

Circuit *4* (Table III) functions as follows:

During positive half-cycles of transformer voltage:

(a). C_1 is charged through T_1 to a voltage equal to E and of the polarity shown.

(b). Since tube T_1 is conducting, at this time, the positive terminal of C_3 is connected to, and is approximately at, ground potential. Tube T_3 starts conducting because the potential of C_2 (C_2 assumed to have been charged on previous cycles) is of the proper polarity, thus placing C_3 in parallel with C_2. C_3 therefore charges to the potential of C_2—that is, to approximately $2E$.

During negative half-cycles of transformer voltage:

(a). The transformer voltage adds to the voltage of C_1 and through T_2 charges C_2 to the sum of these voltages—to approximately $2E$.

(b). Since tube T_2 is conducting, at this time, the positive terminal of C_3 is connected to, and approximately at, the potential of the positive terminal of C_4. Tube T_4 starts conducting, because the potential of C_3 is of proper polarity, thus placing C_4 in parallel with C_3. C_4 therefore charges to the potential of C_3—to approximately $2E$.

Since C_2 and C_4 are connected series additive, the output voltage between terminals G and L_4 is approximately equal to $4E$.

Single-way, Odd Multiplier

By grounding terminal X instead of terminal G, d-c voltages that are approximately odd multiples of the peak voltage of the d-c winding will be obtained between ground and the odd-numbered L terminals.

If the ground is left at G, as indicated in Circuit *4* (Table III), a voltage having an average value of an approximate odd multiple of the peak voltage of the d-c winding is produced between ground and the odd-numbered L terminals; but this voltage to ground has a ripple, as indicated in **Fig. 9(b)**.

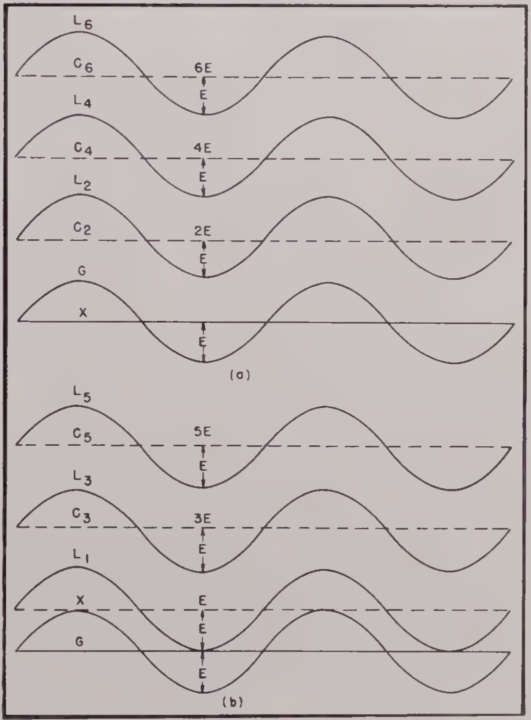

Fig. 9. Ripple voltages for Circuit *4:* (a) for even multiplier with ground at X; (b) for odd multiplier with ground at G

Fig. 10 shows types of voltage-tripler and -quadrupler circuits that are a variation of the circuits shown in Table III.

These circuits operate as follows: Referring to **Fig. 10(a)**, T_2 and T_3 conduct during each positive half-cycle and charge capacitors C_2 and C_3 to approximately E_{peak}. During each negative half-cycle, T_1 conducts, and the secondary-winding voltage E adds to the voltage of capacitor C_3 to charge C_1 to approximately $2E_{peak}$. This charging action is the same as occurs in Circuit *1* (Table III).

In the quadrupler circuit in **Fig. 10(b)**[(h)], the charging sequence for C_1 and C_3 is the same as explained for circuit in **Fig. 10(a)**. Also, this same charging sequence applies to C_2 and C_4 except that the action occurs on the following half-cycle from the corresponding action with C_1 and C_3.

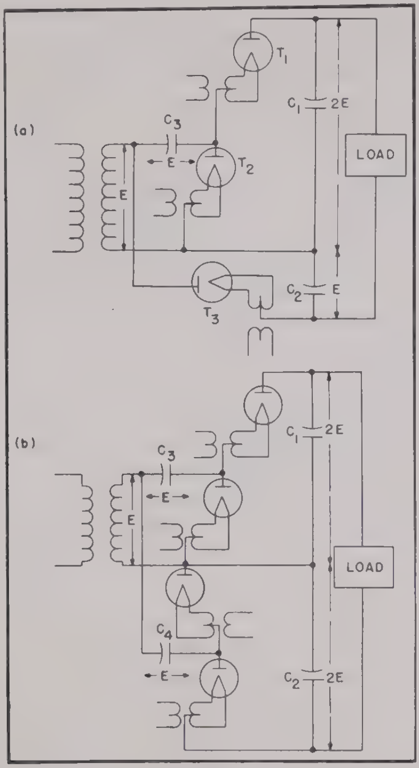

Fig. 10. Variations of circuits shown in Table III: (a) voltage-tripler circuit; (b) voltage-quadrupler circuit

Fig. 11 shows an alternative single-way voltage-multiplier circuit. Depending on the number of stages used, the voltage across the last capacitor will be an approximately even or odd multiple of the rectifier-winding peak voltage. This circuit is an alternative to Circuit *4* (Table III). It functions in the same manner as explained for Circuit *4*, but, because of the difference in connection of the capacitors, the total voltage added by the preceding stages is applied to the capacitor in the next stage. The inverse voltage applied to each tube is *E*. Since half of the capacitors are connected to one common point and half to another, each set of capacitors may be combined in a single unit, provided proper precautions are taken to prevent internal leakage between terminals.

Double-way, Even Multiplier

Circuit *5* (Table III) is a double-way circuit for obtaining d-c voltages that are approximately even multiples of the d-c winding peak voltage.

The sections to the ri[illegible]he secondary winding are the same as for Circuit *2* ([illegible] III), and the sections to the left are images of the sections to the right.

Each of the sections operates as explained for voltage-doubler circuits. The secondary winding operates on alternate half-cycles with the sections to the right and to the left. The circuit therefore functions as a double-way rectifier.

The voltage produced between terminals L_1 and L_2 is a d-c voltage that is approximately four times the rectifier-winding peak voltage. Each additional section, either to the right or the left side, as shown in Circuit *5* (Table III), adds a d-c voltage that is approximately twice the peak of the d-c winding voltage.

A section may be added to only one side if it is desired to increase the voltage by approximately $2E_{\max}$, but in this case a fundamental component of a-c voltage will appear in the output voltage. This is caused by the unequal loading of the d-c winding on the two half-cycles that results from the unequal number of stages in the right and left portions of the circuit.

Double-way, Odd Multiplier

Circuit *6* (Table III) is a double-way circuit for obtaining d-c voltages that are approximately odd multiples of the peak voltage of the d-c winding. This circuit is the same as Circuit *5* (Table III) except that the sections to the left have been inverted.

With this connection, d-c voltages that are approximately three times that of the d-c winding peak voltage can be obtained between L_1 and L_2 and between L'_1 and L'_2. Each additional section, either to the right or to the left side, as shown in Circuit *6* (Table III), adds a d-c voltage that is approximately twice the peak of the d-c winding voltage.

By a proper choice of the *L* terminals, voltages that are approximately odd multiples can be obtained from Circuit *6* (Table III). Between L_1 and L'_2, and also between L'_1 and L_2, there is produced a voltage that varies from *E* to *3E* and has an average value equal to approximately *2E*—that is, because of the d-c winding voltage, there is a ripple equal to *E*.

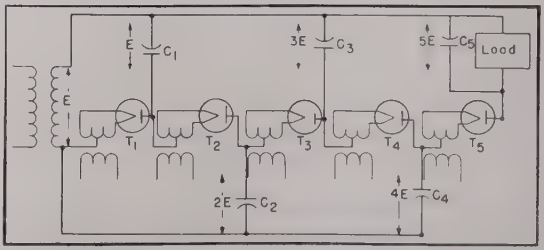

Fig. 11. Single-way multiplier circuit, an alternative to Circuit *4* (Table III)

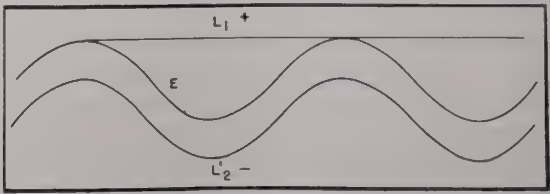

Fig. 12. Voltage between L'_1 and L'_2 in Circuit *6* (Table III)

The wave shapes of the voltages between L_1 and L'_2 are shown in **Fig. 12**.

[(h)] For a detailed explanation of thi[illegible] t the Voltage Tripling and Quadrupling Rectifier Circuits, [illegible] H. A. K. Toskin, *Proc. IRE*, July 1945, p. 449.

As additional sections are added to the left and right, the average value of the voltage will increase in steps equal to approximately $2E$ and will have a ripple equal to E if taken between primed and unprimed terminals of Circuit *6* (Table III).

Multiplier vs. Series Circuits

In voltage-multiplier circuits, much of the power is handled by capacitors. This limits the application to cases where the load current is not more than a few milliamperes. It should be noted that each capacitor must be large compared to those farther from the d-c winding, and all must be large compared with the load, if a degree of multiplication approaching the theoretical maximum is to be obtained.

For example, for Circuit *4* (Table III) to deliver 3 ma at 100 kv between terminals G and L_4, the capacitance values should be approximately as follows:

$C_1 = 0.04\ \mu$f, 25 kv; $C_2 = 0.02\ \mu$f, 50 kv;
$C_3 = 0.02\ \mu$f, 50 kv; $C_4 = 0.02\ \mu$f, 50 kv.

The d-c winding of the transformer would be rated approximately 20 kv rms, 0.025 amp. There would be approximately a ten per cent peak-to-peak ripple in the output voltage. Either larger capacitors or, preferably, a choke and capacitor filter would be required if the ripple must be reduced to a low value.

It is evident that if the multiplier circuit is to handle more than a few milliamperes, the cost of the capacitors may outweigh the savings in the transformers. In all applications, increasing the a-c supply frequency reduces the capacitor kva required.

For higher currents, the alternative is to use a circuit that is composed of voltage-doubler circuits in a series arrangement.(6) If the voltage is very high, the series doubler circuit is preferable to a multiplier circuit, even for small currents, because of the simplification of filament supply and insulation and the superior regulation characteristics.

For moderate-voltage and small-current applications, the availability of tubes of proper current and inverse-voltage rating are important factors in determining the choice of circuit. The cost and size of high-vacuum tubes are determined largely by their inverse-voltage rating. They are usually rated for several hundred milliamperes and require a relatively high-capacity filament supply. If the required output is only a few milliamperes, a number of low-current moderate-inverse-voltage rectifier tubes used in a multiplier circuit usually will be found to be more economical than one or two high-voltage rectifier tubes in a doubler circuit.

Thus, in general, multiplier circuits are preferable for high-voltage rectifier applications of a few milliamperes, and series or cascade circuits are preferable for larger current and for all very-high-voltage applications. For relatively large current applications, conventional rectifier circuits are preferable to multiplier circuits.

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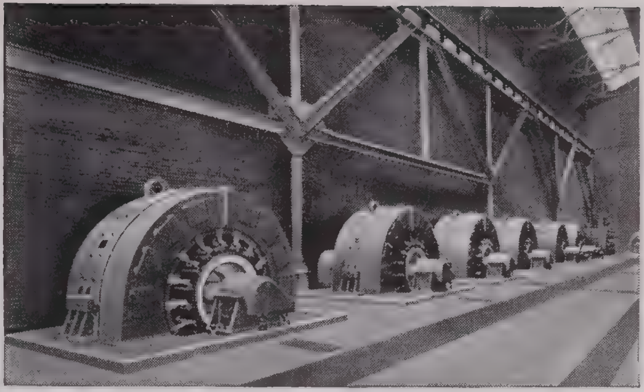
(6) "1,400,000-volt Constant Potential X-ray Equipment," by E. E. Charleton and H. S. Hubbard, General Electric Review, July, 1940, p. 271.

(To be continued)



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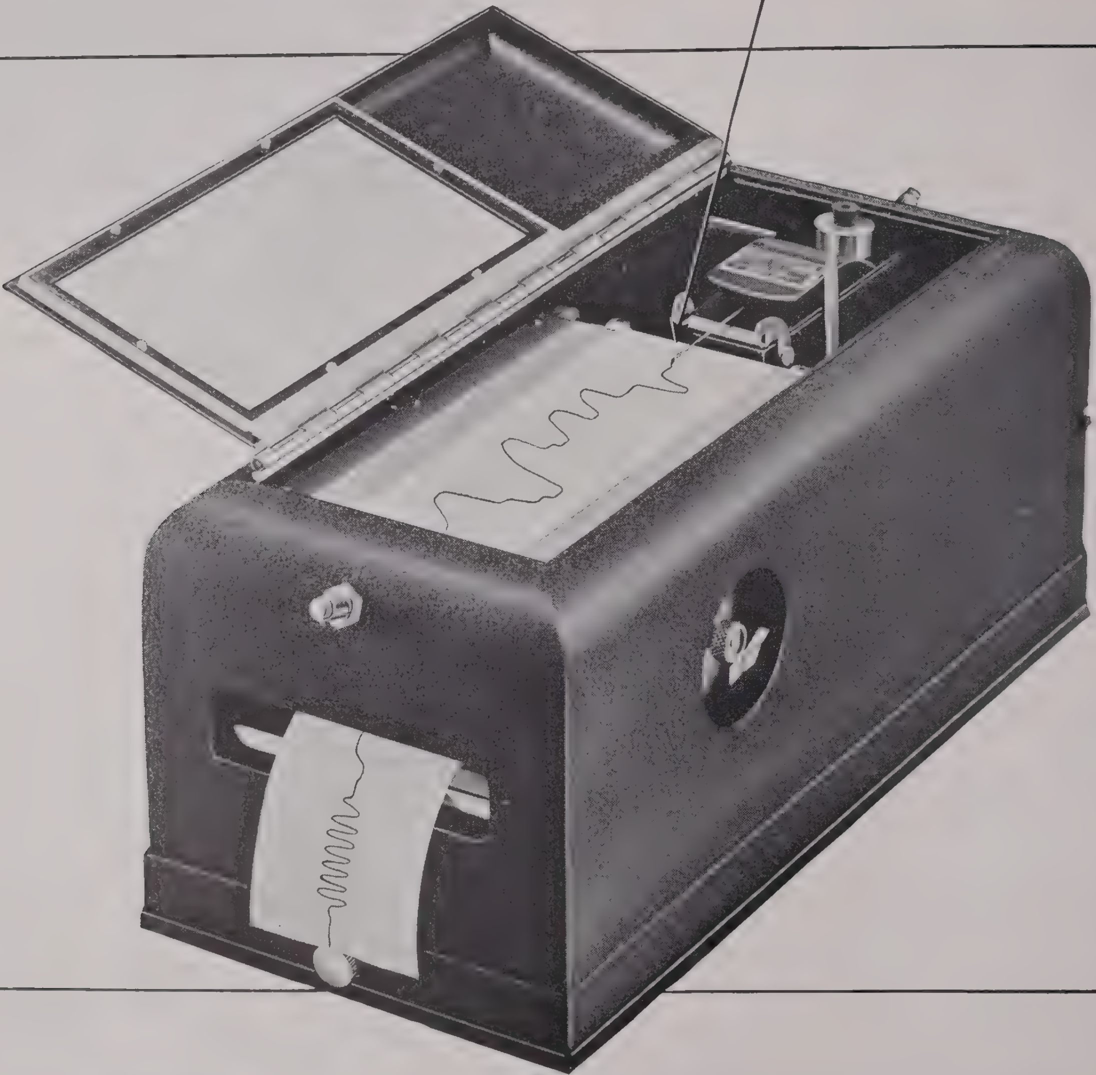

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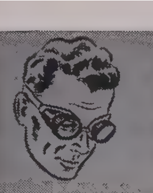
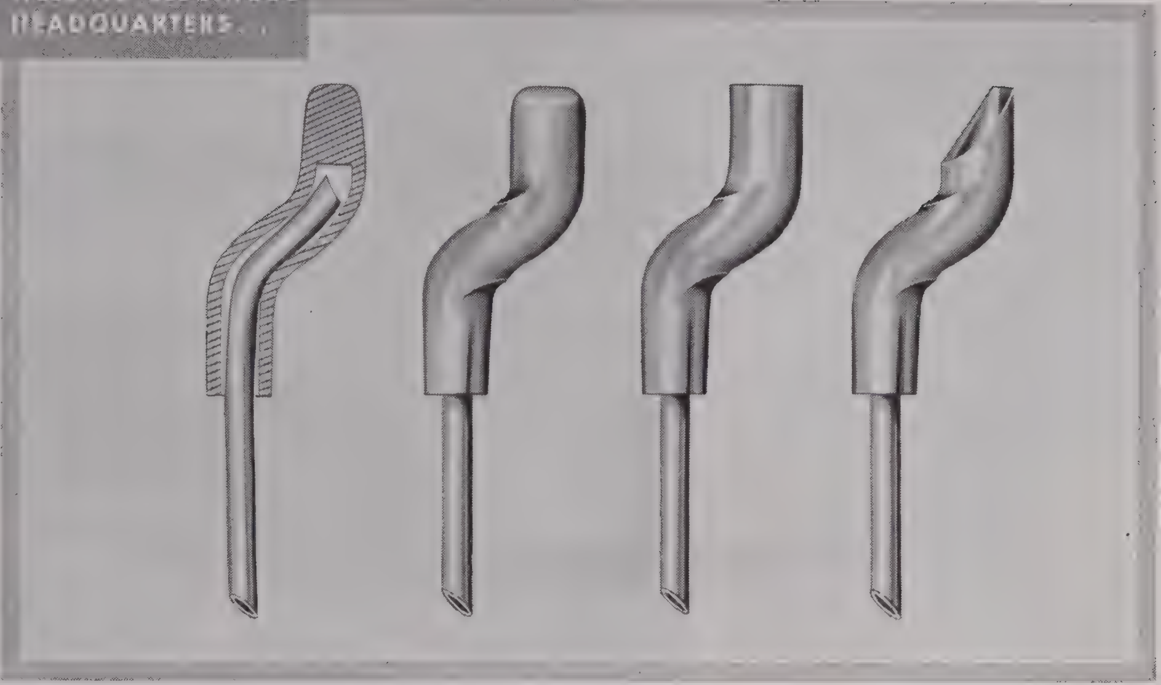
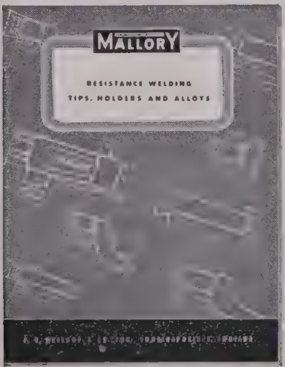


Another NEW Product from
RESISTANCE
WELDING ELECTRODE
HEADQUARTERS . . .



Plan a Wider Range of Work With New
MALLORY WATER-COOLED OFFSET ELECTRODES†



MALLORY
RESISTANCE WELDING
TIPS, HOLDERS AND ALLOYS

First check our new 1948 catalog—

"Mallory Resistance Welding Tips, Holders and Alloys".

It contains everything you want to know about Mallory standardized welding electrodes, holders, replacement parts, accessories, seam welding wheels, dies, and special alloy applications for Resistance Welding.

If it isn't there—get in touch with Mallory direct.

MANY unusual jobs can be resistance welded more economically with the new Mallory offset, Water-Cooled Electrodes. The four standard nose-shapes shown are available in Elkaloy A*, or Mallory 3* metal, with brass water tube bent in place, formed to any offset length to meet your specific requirements.

SPECIFICATION DATA

1. Amount of offset center line to center line can be varied from ⅛″ *to a recommended maximum of* 1½″.
2. *More economical* since they are bent from standard stocked electrodes in #1 and #2 Morse tapers.
3. *Give better welding life* due to the bringing of essential cooling water right to the welding face.
4. Can be supplied *with* or *without brass water tube.* Brass tube replaces the standard sliding water tube found in all Mallory holders. All electrodes supplied with .245″ diameter tubes extending 2″ from bottom of electrodes unless otherwise specified.

Send in your requirements. We will welcome the opportunity to supply samples and prices. Mallory is continually developing such improvements as these water-cooled electrodes represent. Mallory investigates life factors of various materials, design, and load carrying capacities of offset holders. Mallory is the only supplier in the field equipped to keep abreast of new developments in its own laboratories.

MALLORY IMPROVEMENTS ARE AT WORK WHEREVER RESISTANCE WELDING IS!

In the United Kingdom, made and sold by MALLORY METALLURGICAL PRODUCTS, LTD. (An Associate Company of Johnson, Matthey & Co., Limited) Hatton Garden, London, E.C.1.

THE PIONEERS OF ELKONITE*, ELKALOY A*, MALLORY 3*, MALLORY 53B and MALLORY 100 METALS.

P.R. MALLORY & CO. Inc.
MALLORY
RESISTANCE WELDING MATERIALS
ELECTRODES—HOLDERS—SPECIAL DIES AND FIXTURES—
ELKONITE* METALS—ALLOY ROD AND BAR STOCK—
FORGINGS—CASTINGS—ACCESSORIES *REG. U. S. PAT. OFF.

P. R. MALLORY & CO., Inc., INDIANAPOLIS 6, INDIANA

†Mallory Patent Pending on Water Cooling Tubes bent in place.

HIGH LIGHTS AND SIDE LIGHTS

Simple Brushing Setup Descales Conveyor Chain

A unique power brushing technique now in use reduces conveyor-chain maintenance costs and offers substantial savings in operating.

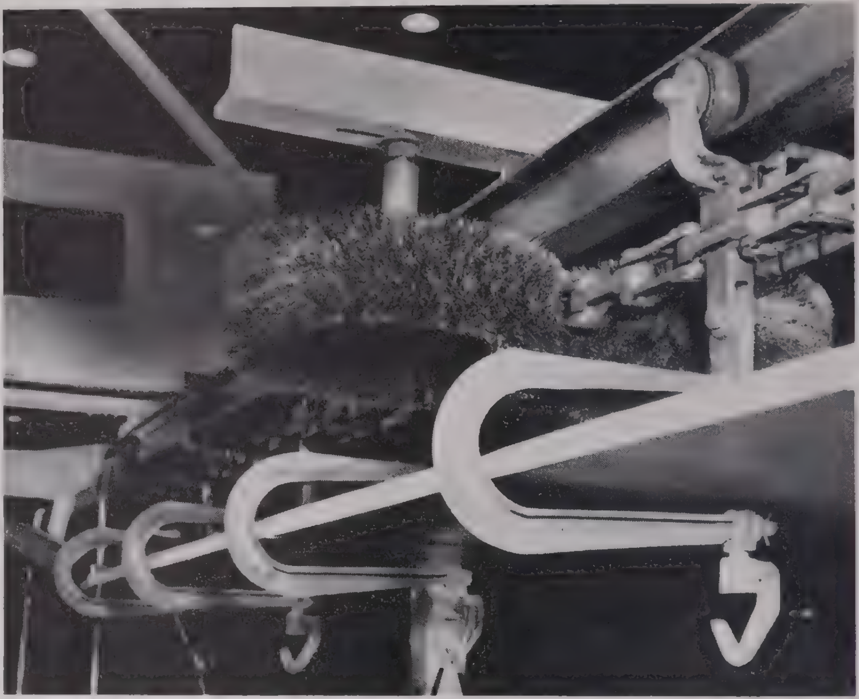
The brushing setup, which operates in conjunction with one plant's new conveyor assembly, is designed to eliminate the problem of scale deposits on the conveyor chain, which passes through a rust-proofing solution at one stage of the assembly.

Two circular wire brush sections of special design are mounted on opposite sides of the conveyor chain, as shown in the photograph, to contact it just after it emerges from the bonderizing bath. Not only the scale deposits are cleaned off, but also excess grease, oil, and dirt which accumulate in regular service.

The plant's conveyor chain is one of the longest in the country and travels at the rate of 27 fpm. Prior to the introduction of the brushing method of descaling the chain, it was necessary to halt production periodically, remove the chain from the conveyor, and clean it in a caustic solution.

The flexibility of power brushing enables it to meet almost any cleaning problem and it can be set up to eliminate the stopping of production while this necessary cleaning is completed.

One of the unusual features about this brushing operation is that no special power mechanism is required to operate it. The brushes revolve with the chain, cleaning it continuously as the production line moves.



This brushing installation, consisting of disk-center circular wire brush sections, keeps conveyor chains free of scale deposits, excess grease, and dirt, thus reducing production interruptions for maintenance and general cleaning

Painting Machine

A new, fully automatic painting machine now in operation cleans, rustproofs, paints, and dries a variety of parts in the record time of one hour and 42 minutes. As many as 12,960 pieces in an hour can pass through this device, which was designed as a solution to the problem of applying an even finish to large quantities of control equipment of different sizes and shapes.

Parts to be painted are hung from a conveyor, which first carries them through a cleaning cycle—washing, hot and cold rinse, rustproofing, another cold rinse, and an acid rinse. They are then borne through a drying oven and a cooling tunnel, and from there into the paint chamber, where a uniform coat is applied. The conveyor passes from the paint chamber into a draining section, where excess paint drips from the parts, and thence into baking ovens for the final step in the process.

An even coat free from flaws is achieved. Paint that drips from the parts in the draining section flows back into the main paint reservoir, keeping waste at the minimum.

Painted articles being removed from the conveyor system on which they were cleaned, treated, painted, and dried

Silicone Golf Ball

Two of the world's latest scientific developments—silicone "bouncing putty" and a human-like electronic thread-winding device—are being used in the production of a new golf ball.

The silicone—new elastic substance derived from sand—is put into the center of the ball to give it improved distance, "click," and "feel."

The electronic device, equipped with an "electric eye" that can detect factors unseen by the human eye, controls the tension of the thread wound around the center, making all balls uniform in playing performance.

Bouncing putty is said to have more resilience than any other substance ever used in a golf-ball center. It is a member of the large family of silicones developed during World War II and in its crude state resembles soft putty.

Tests conducted by professional golfers and scientists indicated that the new ball gives more distance than other balls in addition to improved "click" and "feel."

Development of electronic winding-tension control will make it possible to produce thousands of golf balls possessing the same degree of resilience.

The winding device consists of a photoelectric tube wired to a system of relays, amplifiers, and other gadgets. A narrow beam of light shines from a tiny bulb through a lens onto the photoelectric tube. The golf-ball thread is in the path of the light and vibrates like the string of a violin. Thus the beam of light is interrupted when the vibrating thread crosses its path, transmitting impulses of light to the photoelectric tube. The tube is adjusted to take the impulses at a preset, uniform frequency. When they come too fast or too slowly, an electronic brake applies correspondingly more or less pressure on the thread, bringing it back into "tune." This checking and adjusting takes place automatically in a fraction of a second, thus keeping the tension virtually constant throughout the winding process.

Solarium of Synthetic Sunshine

At Atlantic City the new rooftop solarium of the Hotel Senator makes a commercial reality of what once was an engineering experiment in making synthetic sunshine.

The installation, of all-glass construction, provides guests with the gentle warmth and beneficial ultraviolet radiation of artificial sunshine regardless of weather outdoors, in winter as well as in summer. Thirty to forty people can relax at one time in the seashore setting and in the atmosphere of a sunny summer day.

This solarium represents a step toward a new horizon in the application of artificially produced components of sunshine. In addition, the hotel has incorporated into its sundeck those environmental factors which contribute psychologically to rest and relaxation—tropical plants, vines, and deck chairs. Soon, perhaps, other hotels, hospitals, schools, institutions, and office buildings will have indoor solaria providing pleasant and beneficial infrared and ultraviolet radiation for increasing numbers of people.

The complete solarium nearly duplicates the three components of sunshine: light, radiant warmth, and that portion of ultraviolet energy which is usually considered good for suntanning without the need of protective dark goggles. The ultraviolet energy is supplied by eight large Uviarc lamps, equipped with suitable filters, and a number of household sun lamps. Radiant infrared is furnished by 192 incandescent lamps arranged on switching circuits which permit variations in heat control for comfort. Approximately 50,000 watts—comparable to the power of a major broadcasting station—are required at full operation.

Since individual persons vary widely in adaptability to tanning effect, the intensity of ultraviolet radiations varies from place to place in the room so that each sunbather can choose a spot suitable to his particular type of skin.

Ultraviolet and infrared light and energy are supplied in this solarium in all weather and all seasons, in intensities to suit all types of skin

Electronic Tracks for Aircraft

Development of a revolutionary air-navigation and traffic-control system called TRICON, which would create aerial superhighways across the country, has been announced.

The system will enable aircraft to fly in five or ten parallel lanes along these aerial highways much the way locomotives traverse railroad tracks.

Electronic engineers are developing the system—first ever devised to integrate traffic control, safety, and navigational functions—to handle as many as 200 aircraft a minute past one point at the speed of 300 mph.

Although this traffic density may not occur for many years, the ability to absorb it makes TRICON a system for the future as well as the present.

The "electronic tracks" can be established two miles apart without danger of collisions and will be created by coinciding pulses of radio-frequency energy sent out by radio transmitters located in 50-mile areas along the aerial superhighways.

The position of an aircraft will be automatically indicated to the pilot while the ground station is notified simultaneously of the location, altitude, and identification of every plane in the airway sector. An automatic block warning system will warn the pilot if the section of the electronic track immediately ahead of the aircraft is occupied.

Basically, the system is similar to that employed by railroads, except that each airplane carries its own navigation and block signal indicator on the instrument panel. Signals from the radio transmitters are intercepted, interpreted, and acted upon by automatic electronic receiving, transmitting, and measuring equipment in the airplane and in the ground station. Meters, indicators, and a series of flashing lights are used to depict this information.

Thus, both the pilot and the airport will know an aircraft's exact position and course regardless of weather conditions.

A special circuit in the aircraft transmitter will allow airport operations to learn the altitude of each aircraft on each safety track. The transmitter modifies its characteristic signal to the ground as the aircraft changes altitude, providing this information to the airport along with its identification code.

Another feature of the TRICON system is the fact that, using the same equipment, the ground station is capable of flashing a series of commands to the aircraft like "hold," "go to track W," "turn left," etc. Lights corresponding to each of these commands will flash on the pilot's instrument panel. No voice communication is used ordinarily, but it may be used in emergencies or for special instructions.

The label TRICON is derived from TRIple COincidence Navigation, for triple coincidences of pulses are the heart of the system.

One of the ground radio transmitters in each 50-mile section of airway is the master station, and it will transmit signals at an unvarying rate of speed—probably about 3000 pulses a second. By delaying or speeding up the pulses from the other two stations, called "slave" units, triple coincidence of pulses are made to occur at successive points along the tracks. The entire 50-mile section is "scanned" with triple coincidence about once a second. The airplane continually establishes its position in the block system and indicates, as in railroading, whether the block ahead is clear. The system can also be coupled to the automatic pilot for automatic flight control.

Equipment for TRICON consists of standard aircraft radio transmitters and receivers, circuits and timers utilized in nuclear research, and relatively simple recording and indicating devices. It is proved equipment which can be linked together for the TRICON air-navigation and traffic-control system.

BACKGROUND TO ACHIEVEMENT

Bombay★

—is today one of the finest cities in the world. Guide books deal faithfully with its architectural features, amenities and historical associations, but largely ignore those "monuments" to engineering enterprise and achievement, the "essential services." Yet the fact is that these services—power, light, water, transport, etc.—are the essential background of this great city: just as BTH is—and for the past fifty years has been—the essential background to many important engineering achievements in scores of big towns the world over.

★ *BTH supplied the electrical equipment of the entire rolling stock of the Bombay suburban line of the Bombay, Baroda and Central India Railway—including the Traction Motors and Control and auxiliary gear, while Mazda lamps provide much of Bombay's lighting.*

BTH **RUGBY**

I.A.107 THE BRITISH THOMSON-HOUSTON COMPANY LIMITED, RUGBY, ENGLAND

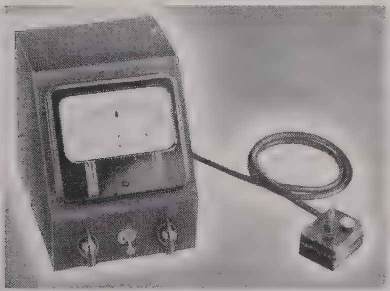
NEW PRODUCTS: AND WHAT THEIR MAKERS HAVE TO SAY ABOUT THEM

Vacuum Unit

This table-model vacuum unit, with a Pyrex bell jar 7 in. in diam and 10 in. long, is capable of producing a pressure of 1/10 of a micron. The unit is complete with mechanical and oil diffusion pumps, a Pirani gauge, four electrodes, and a power circuit. When charged with a nonvaporizing load, the 7-in. bell jar will attain a vacuum of 3×10^{-4} in less than 20 min, and will reach 1×10^{-4} under an hour. The optional 12-in. bell jar will reach 5×10^{-4} in about 1 hour. Some of the applications are: coating lenses and mirrors with low reflecting surfaces; preparing surface replicas for the electron microscope; metal evaporation; classroom demonstrations; and electronic experiments —*Distillation Products, Inc., 755 Ridge Road West, Rochester 13, N. Y.*

Micrometer

A new dual-purpose electric micrometer, in addition to the usual measuring and gaging operations, performs telemetering where remote indication of small movements is wanted. The micrometer is arranged for battery operation. It consists of a transmitter unit and a control unit, together with connecting cable. The transmitter is a sealed unit having a projecting plunger which will accept motions of ± 0.010 in. from the center position, or 0.020 in. total in one direction. This mechanical motion is translated, inside the housing, into changes in electrical energy which are then sent to the control unit.—*Stevens-Arnold Inc., 22 Elkins St., South Boston 27, Mass.*



Packaged Solder

Two new small handy packages of 3-cored Ersin Multicore solder simplify use of the solder, making for greater economy.

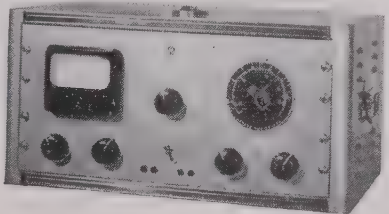
This solder is made of noncorrosive flux in gages between 10 and 22 s.w.g. and in five antimony-free alloys, each package being clearly marked as to size and alloy.

The 1-lb package features a novel pull-as-required arrangement which adds speed and convenience, and eliminates wastefulness in use.

The small Handy-Pack is designed for the small-quantity and home users.—*British Industries Corp., 315 Broadway, New York.*

Distortion and Noise Meter

A new distortion and noise analyzer, Type YDA-1, for broadcast, television, research, and developmental applications. Combining four basic functions, the unit will: measure percentage distortion down to 0.1 per cent; measure the hum or noise present in an audio signal; act as a high-sensitivity vacuum-tube voltmeter; and perform as a frequency meter over the range of 50 to 15,000 cycles.

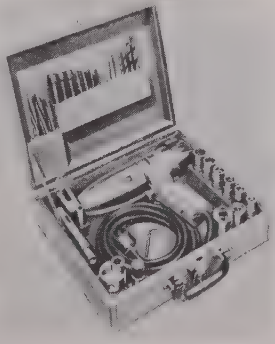


Distortion ranges of 1, 3, 10, 30, and 100 per cent full scale are provided. The noise range is from +2 to −80 db (referred to 1 milliwatt on 600 ohms). The noise frequency bandwidth is 30 to 30,000 cps on 600 ohms balanced input, and 30 to 75,000 cps on 100,000 ohms unbalanced input.

When used as a vacuum-tube voltmeter, the same db range is used, corresponding to inputs between 1 volt and 80 microvolts. —*Specialty Division, General Electric Co., Electronics Park, Syracuse, New York.*

Tool Kit

A new all-purpose portable tool kit provides in one compact unit the necessary equipment for a multitude of utilities service and repair jobs. The kit includes a motor-driven impact tool, plus standard accessories. By using the proper accessory, the service man can perform the following jobs with the impact tool: nut-running and nut-removal; drilling steel, brick, masonry, and wood; reaming and tapping; running wire brush; applying and removing studs; and driving and removing screws. Weighing only 6½ lb, and easy to handle, the tool can be plugged into any a-c or d-c socket and run as any electric tool; when the going becomes difficult, the impact mechanism automatically functions and delivers 1900 rotary impacts per minute.—*Ingersoll-Rand Co., 11 Broadway, New York 4, N. Y.*

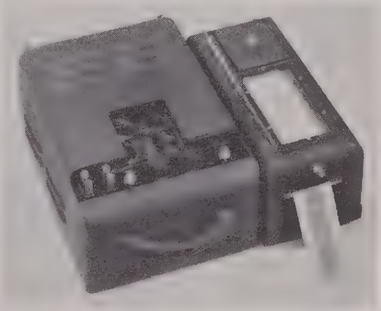


Polar Recorder

A new polar-coordinate recorder identified as the A.I.L. Type 116, designed to plot aircraft-antenna radiation patterns, records voltage on either a linear or a logarithmic scale as radial distance against angular position. The device will be custom-built to each customer's specific requirements. Provision of a permanent-ink record (readily reproducible), rapid writing speed coupled with low pen overshoot, and preciseness of angular positioning are the recorder's outstanding features. Adaptable to any measurement task recordable in terms of polar coordinates, it can be provided in either portable or rack-mounted form.—*Airborne Instruments Laboratory, Inc., Mineola, N .Y.*

Strain Amplifier

The BL-310 amplifier, when used with the magnetic direct-inking oscillograph, is a complete package unit for the measurement of strains. It can be simply operated, producing records which are immediately available and easily interpreted. The equipment records either static or dynamic strains, having a frequency-response range up to 100 cps; direction, as well as magnitude, of the measured strain can be read from the chart. Although primarily intended for use with the SR-4 120-ohm strain gage, it is also applicable for use with any resistance-sensitive pickup.—*The Brush Development Co., 3405 Perkins Ave., Cleveland 14, Ohio.*

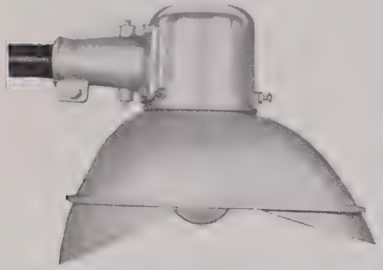


All-purpose Cement

Plastics, wood, metal, rubber, leather, crockery, glass, mirrors, and labels can now be easily adhered to themselves or to each other on an efficient production-line basis by a versatile vinyl-base cement called Rez-N-Glue. This transparent water-white cement dries fast but not too fast for handling large pieces, and it does not affect the material it is applied to, mirrors and thin plastics included. It requires only a one-surface application, has good wet "grab," remains permanently flexible, and will not become brittle. Easily applied by brush, roller, or spray, this adhesive is resistant to water, oil, gasoline, vermin, and mold.—*Schwartz Chemical Co., Inc., 326 West 70th St., New York 23, N. Y.*

Reflector Hood

A new hood, Form 107, designed for high-efficiency reflectors for suburban street lighting. The diecast aluminum hood with a side-mounting slip fitter for 1¼-in. pipe is interchangeable with older design reflectors. It can be set for the 1000-lumen lamp having a light-center length of 4⅜ in. or the 2500-lumen lamp having a light-center length of 5¼ in. This can be done in a few seconds, using only a screw driver. The lamp position, when set, is maintained accurately and rigidly, thus assuring proper focus in the optical system of the luminaire. The hood fits any of a large variety of brackets and mast arms commonly available.—*Lighting Division, General Electric Co., Schenectady 5, N. Y.*



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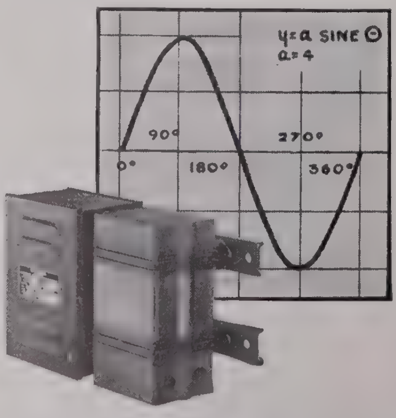
Tachoscope

A nonmagnetic chronometer and speed indicator combined into one small efficient direct-reading instrument. Timing is automatic and a stop watch is not needed. One button is used for simultaneous operating and zero setting. The instrument indicates per-minute speeds automatically, revolutions per minute and, by means of wheel attachment, feet per minute. Type A (three-seconds indicator) has a range of 0 to 20,000 rpm; Type B (six-seconds indicator) a range of 0 to 2,000 rpm. With ½-ft circumference wheel, the dial readings are halved to give surface speeds in feet per minute. The device, designed for testing speeds of motors, engines, turbines, textile machines and other rotating or traveling machinery, is free running and requires no power for driving.—*O. Zernickow Co., 15 Park Row, New York 7, N. Y.*

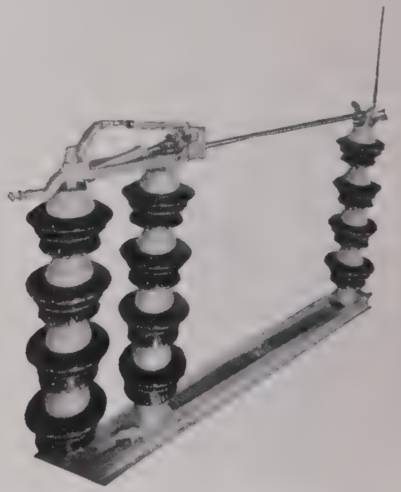
Transformers

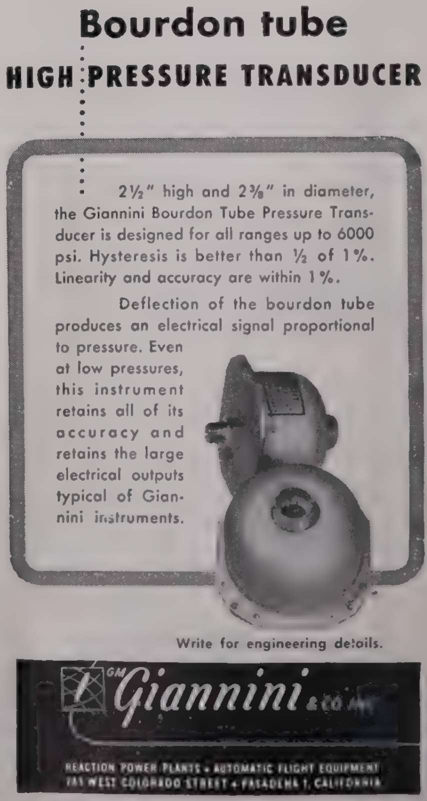
A new line of transformers, Type CVH, designed to deliver a constant output voltage having low harmonic distortion. These transformers are compact, economical units employing no moving parts. Equipped with an additional circuit component which neutralizes the harmonics normally present in the output of constant-voltage transformers, the units produce a stabilized output containing less than three per cent total harmonic distortion. Since the output-voltage wave of these transformers is essentially sinusoidal, the transformers can be used as a source of stable voltage for exacting applications.—*Sola Electric Co., 4633 W. 16th St., Chicago 50, Ill.*



Disconnecting Switches

A new line of group-operated disconnecting switches, designated Type RF, for 115- to 230-kv outdoor service features silver-to-silver line-pressure contacts, a simplified operating mechanism, and complete elimination of current-carrying braids. On the hinge end of the switch, the silver surface of the movable blade engages the silver surface of a U-shaped clip which is backed by adjustable stainless-steel compression springs. This assures a positive contact during opening and closing operations, and prevents burning of the switch. The main moving parts of the switch are equipped with anti-friction bearings, and the blade is fully counter-balanced for all positions.—*Switchgear Divisions, General Electric Co., Schenectady 5, N. Y.*





Bourdon tube
HIGH PRESSURE TRANSDUCER

2½" high and 2⅜" in diameter, the Giannini Bourdon Tube Pressure Transducer is designed for all ranges up to 6000 psi. Hysteresis is better than ½ of 1%. Linearity and accuracy are within 1%.

Deflection of the bourdon tube produces an electrical signal proportional to pressure. Even at low pressures, this instrument retains all of its accuracy and retains the large electrical outputs typical of Giannini instruments.

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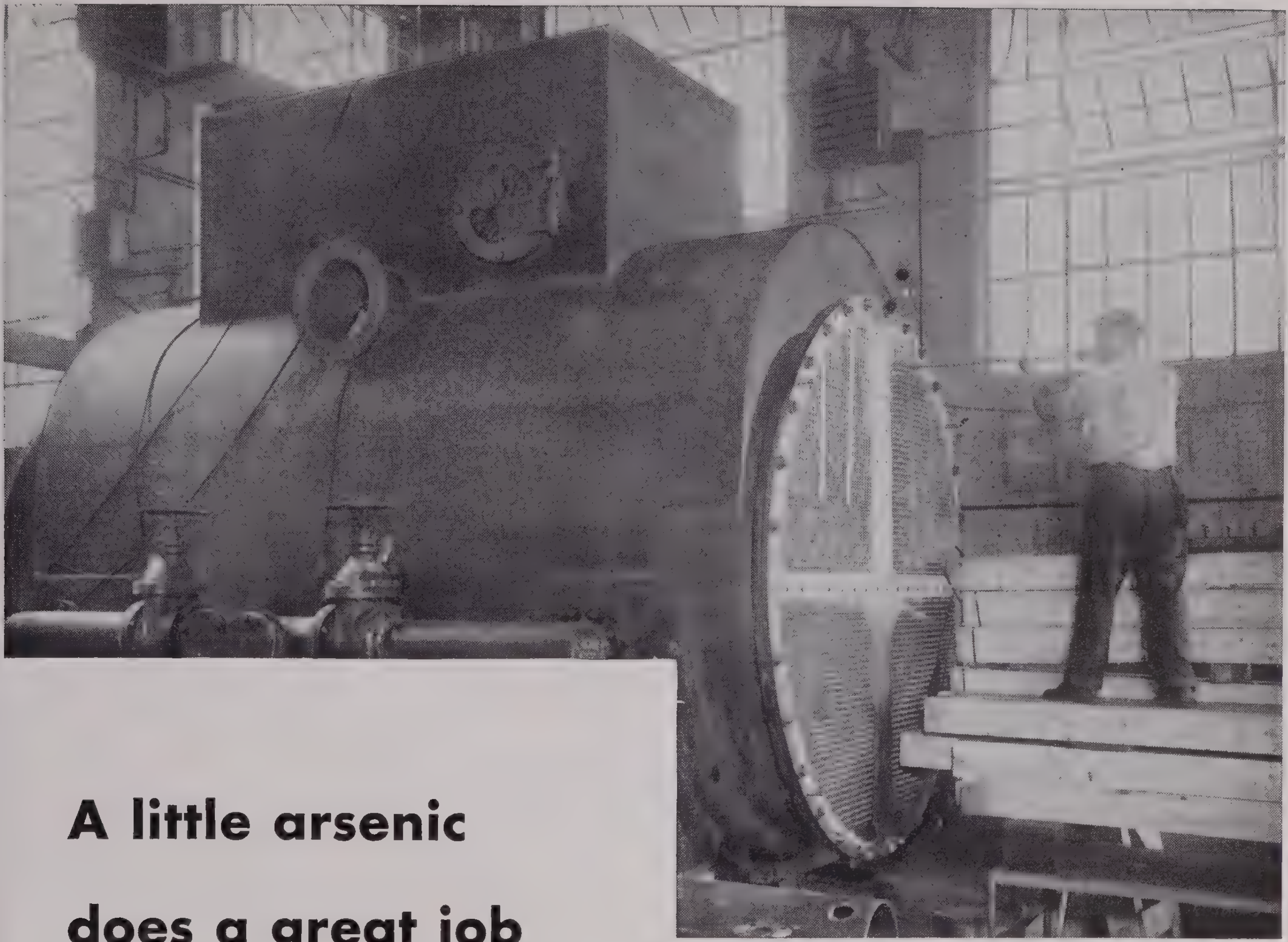

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...increasing resistance to dezincification

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Illustration shows Anaconda Arsenical Admiralty Tubes going into a new condenser being built for a Missouri utility by the C. H. Wheeler Manufacturing Co. in Philadelphia. This dual-bank, two-pass type condenser, has a surface area of 11,000 sq. ft. and a capacity of 77,000 pounds of steam per hour. Tubes are ¾″ O.D. x .049″ wall and 16′ 2⅜″ long. Tubes sheets are Anaconda Muntz Metal—1⅛″ thick x 104″ diameter.

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POWER SYSTEM STABILITY

Volume I

By EDWARD W. KIMBARK
Professor Electrical Engineering
Northwestern University

This new book tackles two important phases of the problem of increasing the reliability of electric power service by keeping instability at a minimum. First, it presents methods of analysis and calculation necessary to determine whether a given system is stable when subjected to a specified disturbance. Second, it examines the effect of various factors on stability and considers measures for improving stability. Emphasis throughout the book is placed on transient stability.

Contents include: The Stability Problem; The Swing Equation and its Solution; Solution of Networks; The Equal-Area Criterion for Stability; Further Consideration of the Two-Machine System; Solution of Faulted Three-Phase Networks; Typical Stability Studies.

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TRADE LITERATURE

Area Meter—Electronically operated area meter—developed to accurately measure the more viscous liquids such as black liquor, tar, chemicals, refrigerants, as well as the freer flowing liquids—is described. Features, principle of operation, and power requirements are some of the subjects covered. Four pages. Bulletin 23B.—*Bailey Meter Co., Cleveland 10, Ohio.*

Radial Guards—Safety equipment for all portable horizontal tools is the subject of this bulletin. Illustrations have parts numbered for identification. Eight pages. Entitled "Make Safety Pay."—*Flohr Safety Equipment, Inc., Buffalo 17, N. Y.*

Cooling Equipment—Cabinet exhaust fan designed for flushing the air of instrument cabinets and radio transmitter cubicles is described. Subjects briefly covered are capacity, Venturi ring, mounting, and motor. One page. Form RP-22—*Rotron Div., Jenckes Knitting Machine Co., Pawtucket, R. I.*

Adhesives—Research aid in choosing adhesives, sealers, and coatings is the purpose of this brochure. Illustrations include such bonding operations as: plywood-to-metal and vinyl sheeting-to-wood; and sealing operations involving aircraft cabins, auto bodies, and boat decks. Included in the 18 case histories are such industries as automotive, aviation, ship-building, oil, and refrigeration. Twenty-eight pages. Entitled "3M Adhesive in Industry"—*Minnesota Mining and Manufacturing Co., 901 Fauquier Ave., St. Paul 6, Minn.*

Welding—Simplified welding techniques for maintenance and repair of a wide variety of metals, forms, castings, and heavy machinery components are set forth in this bulletin. Specialized methods involving welds made below base metal heat of fusion through surface alloying are described in detail. Photographs and diagrams illustrate step-by-step operation; brief case histories are given. Four pages. Railroad Salvage Bulletin R.—*Eutetic Welding Alloys Corporation, 40 Worth St., New York 13, N. Y.*

Overhead-line Splicing—Beryllium copper-lined splices for overhead lines is the subject of this technical bulletin. Sizes of the splices are shown for copper, Copperweld full tension, and loop service. Installation tool data and performance facts complement the text material. Also described are connectors for dead-end connection of overhead lines to disk-type insulators, and line-repair sleeves for restoring broken stranded cable. Eight pages. Bulletin No. 48Y1.—*Burndy Engineering Co., Inc., 107 Bruckner Blvd., New York 54, N. Y.*

Disconnecting Switches—Outdoor hook-operated switches used as isolating devices for lightning arresters, cable potheads, transformers, and circuit breakers, where the switch is not required to interrupt current, are described and illustrated. Design and construction features are given, and rating charts included. Six pages. GEA-4911.—*Apparatus Dept., General Electric Company, Schenectady, N. Y.*

Electrical Connectors—This catalog contains a broad coverage of electrical connecting devices, with specifications, illustrations, and suggestions for inspection, installation, and maintenance. Each product is illustrated with half-tones, diagrammatic sketches, and cutaway photographs. Thirty-two pages. Catalog No. 16.—*Howard B. Jones Div., Cinch Mfg. Corp., 2460 W. George St., Chicago 18, Ill.*

Air Conditioning—This engineering and application data book describes equipment used in the recovery of stale, vitiated, or contaminated air. The bulletin contains information about the selection of equipment; other subjects covered are the system's function, construction, application, operation, and service. Sixteen pages. Bulletin 105-A.—*W. B. Conner Engineering Corp., 114 East 32nd St., New York 16, N. Y.*

Welding Equipment—The resistance-welding tips, holders, and alloys described in this catalog are illustrated with photographs, diagrams, and specification charts. Among the special features is a section describing the physical and mechanical properties of special electrode alloys and their application. A chart indicates recommended electrode materials for spot-welding similar and dissimilar metals. Forty pages. Form No. M-400-D—*P. R. Mallory and Co., Inc., Indianapolis 6, Indiana.*

Torque Control—The three parts of this remote torque-control system—transmitter, torque unit, and amplifier—are described. Typical performance curves indicate the behavior of the unit with varying loads. A schematic diagram shows the arrangement of a typical system. Dimensional drawings are given for each of the three units. Eight pages. Bulletin 711-21—*Eclipse Pioneer Div., Bendix Aviation Corp., Teteboro, N. J.*

High-voltage Cable—Physical and electrical properties of super coronol cable are presented with text material, tables, and performance curves. Photographs show the results of heat-resistance tests. Four pages. GEA-1788D—*Apparatus Dept., General Electric Co., Schenectady, N. Y.*

Lighting—For those interested in cost-cutting of production through improved lighting, this booklet-folder combination recommends a procedure, and provides a guide for foot-candle levels and illustrations for various lighting applications. The bulletin is six pages. Form LMP-148-60M. The folder, twelve small-size pages, is entitled "Balanced Lighting."—*Fostoria Pressed Steel Corp., Fostoria, Ohio.*

Low-resistance Measurement—This instruction manual gives complete directions for the operation of the Ducter, a low-resistance ohmmeter, for application to a wide range of uses. Comments on certain equipment to be tested such as cable and conductor joints, oil circuit-breaker assemblies, and rotating equipment include such subjects as useful formulas, sources of trouble, and procedures in testing. Price fifty cents. Forty-eight pages. Form No. 24525.—*James G. Biddle Co., 1316 Arch St., Philadelphia 7, Pa.*

Welding Symbols—The 1947 Standard Welding Symbols, a revision of the 1942 Standard, covers 34 of the processes used in various industries throughout the country. The method of presentation has been revised from a form of rules to a step-by-step presentation in lecture-type form. The rules have been expanded to include a means of indicating welds having rust penetration. Other features are: the dropping of the confusing terms "near side" and "far side" from the nomenclature; the addition of 45 illustrations showing the various applications of the symbols; and a chart which provides a compact summary of the use of the welding symbols, for ready reference. Price fifty cents. Seventy pages. Entitled "Standard Welding Symbols; 1947."—*American Welding Society, 33 West 39th St., New York 18, N. Y.*

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- Two separate, completely independent, electron guns.
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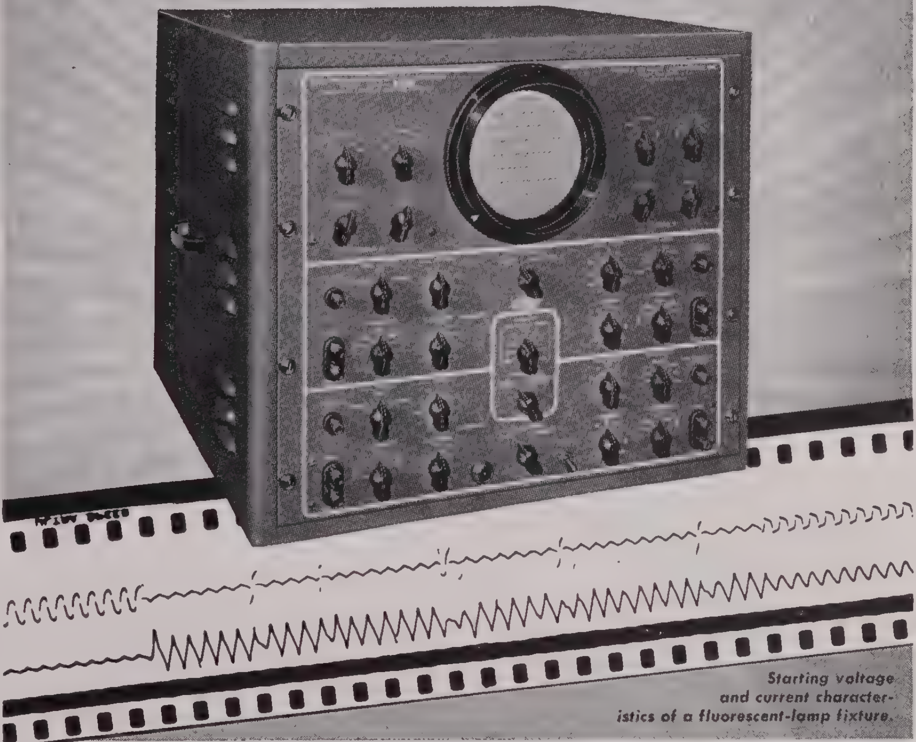

Starting voltage and current characteristics of a fluorescent-lamp fixture.

The introduction of the Type 279 Dual-beam Cathode-ray Oscillograph makes available for the first time a really dual instrument with *separate and wholly independent* electron guns. The circuits associated with each gun are also distinct and separate. For the first time, separate time bases are provided for each beam with provision for applying one time base to both guns, if so desired. For the first time, an oscillograph is offered which alone can perform the applications listed.

Now it is possible to superimpose two complete traces without a cumbersome and costly optical system or by the use of time-sharing devices. And with the P2 screen, the light output is more than sufficient for visual observation or for photographic recording of high-speed transients.

Other advanced features are the built-in calibrator and the ability to respond to direct-current signals.

Descriptive literature on request.

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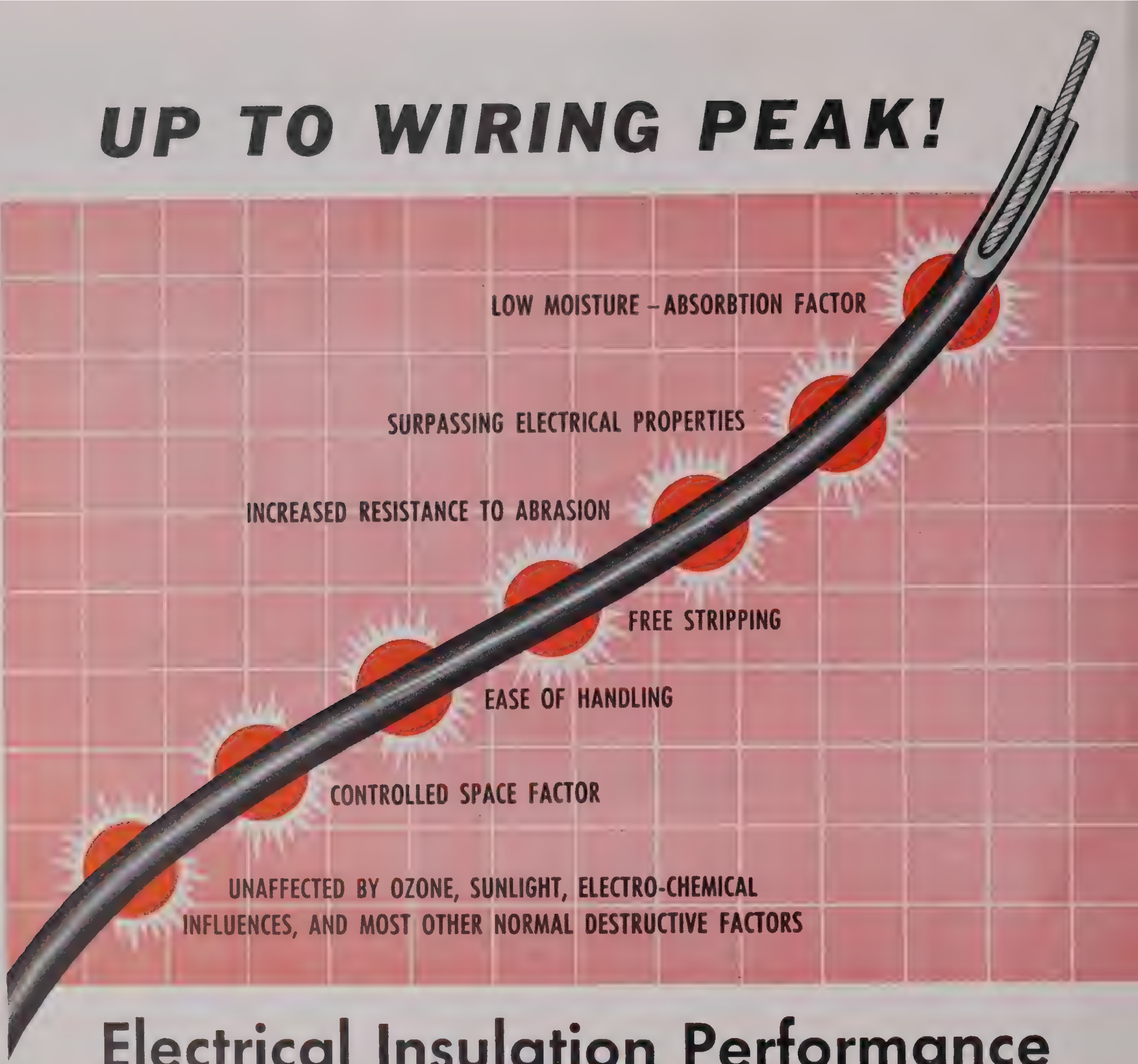
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BOOK REVIEWS

(Available books may be purchased through the GENERAL ELECTRIC REVIEW *for domestic delivery; none sent on approval.)*

I. E. S. Lighting Handbook

Edited by R. W. McKinley—Illuminating Engineering Society, New York. 1947. 856 pp. $7.50.

The long-standing need for a complete compilation of lighting data is fulfilled by this handbook. It places conveniently within reach of the reader a summary of pertinent lighting knowledge accumulated through the years. This information is evaluated and interpreted with respect to today's needs by a qualified group of over 100 contributing specialists—engineers, physicists, architects, decorators, artists, and eye specialists. To broaden the scope of the condensed handbook treatment, each chapter is concluded by a long list of references of original literature which allows the reader to further investigate subjects of particular interest. An unusually large number of photographs and illustrations is included throughout to clarify and amplify points of particular importance.

The book logically begins with a treatment of the fundamentals of light and lighting, including the various types of sources, the control and measurement of light, and the methods of calculating illumination. This reference section provides the reader with a foundation of basic technical information and time-tested application techniques. Following this are several sections devoted to the various aspects of interior, exterior, sports, transportation, photographic, and television lighting, along with applications of infrared and ultraviolet energy. Also included is a section on miniature lamps and their many uses. These application sections provide a fairly complete description of the illumination requirements for the various lighting fields, and the methods by which they can be fulfilled. To further aid the lighting designer in making his recommendations, the Manufacturers' Reference Data section furnishes detailed engineering information on many types of commercially available lighting equipment.

The handbook covers the field quite thoroughly and the wealth of data it contains should make it invaluable not only to those in the lighting field, but also to architects, interior decorators, consulting engineers, eyesight specialists, teachers, and others interested in the humanitarian aspects of light and lighting.

HERBERT R. KAEWERT

Fluid Mechanics of Turbo Machinery

George F. Wislicenus—McGraw-Hill Book Co., Inc., New York. 1947. 630 pp. $7.50.

Intended to serve as an advanced textbook as well as a reference work, this book covers adequately the theory of fluid-flow machinery in the incompressible field and offers as well considerable material on compressible flow. Consideration of practical deviations from theory is limited to hydraulic pumps, these being, as the author states, the field of his experience. Conditions for similarity and the effect of Reynolds' number are clearly stated. There is a good description of cavitation.

A section on hydraulic couplings and torque converters is included, as well as an interesting treatment of "ducted" propellers.

Beyond the simple theory, nothing dealing with turbines is contained in the book, which is to be regretted, since this reviewer knows of no modern work covering theory and practice on turbines as well as this one covers pumps.

Enclosed in the book are a shock polar diagram and a hodograph for supersonic airflow calculations, a chart of thermodynamic properties of air, and a chart of characteristics of turbines in specific speed, flow, etc.

P. H. KNOWLTON

Radar Beacons

Edited by Arthur Roberts, Office of Scientific Research and Development, National Defense Research Committee—McGraw-Hill Book Co., Inc., New York. 1947. 489 pp. $5.00.

This is Volume 3 of the Massachusetts Institute of Technology Radiation Laboratory Series and represents a very comprehensive treatment of the various types of radar beacons.

It is unique in that it is the only book ever published on that subject.

While necessarily based upon the intensive beacon developments of wartime, enough background, design data, and operational information is given to enable the prospective peacetime user to choose the proper beacon system for his navigational requirements.

The text is divided into four major parts: Basic Considerations; Beacon Design; Interrogator and System Design; and Beacons in the Field.

Because *Radar Beacons* is alone in its field, and since it is so complete in its coverage, it is likely to serve as a beacon designer's bible for some time to come. Its influence will be strongly felt upon the design and placement of beacons as navigational aids to commercial planes and ships.

It is to be hoped that the editors will ultimately undertake a treatment of Ramark beacons, perhaps developed too late for inclusion. Low cost and simplicity make probable the widespread use of this noninterrogated type of beacon for certain of the navigational problems.

The beacon motto quoted in the text is interesting and significant:

"They also serve who only stand and wait."

L. H. LYNN

The Electrical Appliance Sales Handbook

Laurence Wray—McGraw-Hill Book Co., Inc., New York. 1947. 231 pp. $3.50.

If the thousands of electric-appliance dealers throughout the country, and their sales people, would study this book and master its contents, a distinct service would be rendered to electrical manufacturers, public utilities, and consumers themselves; for it contains a wealth of data on operating costs, advantages to the housewife and farmer, and the economies that can be secured.

Special emphasis is laid upon electric appliances on the farm, including water supply and the various electrical aids. The author has for years been associated with a magazine devoted to the electric-appliance trade and has access to information which may be presumed to be accurate and up-to-date.

The book is free from high-pressure sales technique and confines its sales arguments to facts and statistics. Unfortunately, even though the book presents much useful information, it is doubtful that any but a small percentage of appliance salesmen will take the time to read it. It is at times rather lengthy and involved, as for example, when the author presents the case for cooking by electricity as opposed to cooking by bottled gas. Nevertheless, the book is a useful contribution and should be on every appliance dealer's shelf.

C. F. SCOTT

The Science of Plastics, Vol. I

Edited by H. Mark and E. S. Proskauer—Interscience Publishers, Inc., New York. 1948. 632 pp. $9.00.

"The Science of Plastics" is an attempt to collect and index the most important papers covered in the abstract service, "Resins, Rubbers and Plastics," by the same authors. The abstracts have been used in their original form with some relocation of them and the provision of a subject index to facilitate finding the information desired.

This book does not appear to cover all of the abstracts in the original abstract service, nor can it be kept up to date easily as the service itself. Except for the index (which does not appear to have been thoroughly checked) the book will be of little value to those persons presently subscribing to the abstract service. To many who do not, it will be a valuable reference book for those specific papers it covers.

In conclusion, it is only fair to comment that the selection of papers covered contains a fairly high percentage of those written by authors associated with the Brooklyn Polytechnic Institute.

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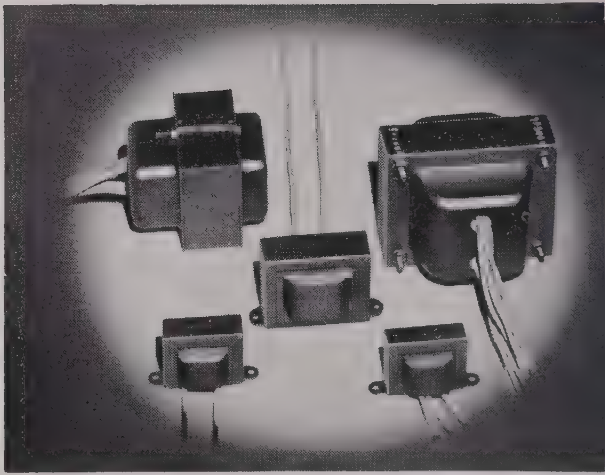


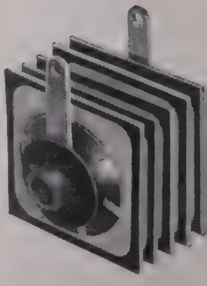
Whatever your transformer needs—power units like these, or special designs for deflection yokes, horizontal or vertical sweeps, or oscillators—General Electric can supply them . . . and quickly. G.E. offers its facilities and engineering "know-how" to television manufacturers in tailoring these transformers to their requirements. Just tell us your specifications and we will meet them to your complete satisfaction. Power-supply transformers are available now in core-and-coil and enclosed-case styles as standard units designed for television applications. Units for other uses are tailor-made from standard parts. Ask your G-E representative for more information; you'll be pleased with the prices and shipments he will offer you.

NEW PYRANOL CAPACITORS SAVE SPACE, WEIGHT, MONEY

If you have been using 600-volt d-c capacitors on circuits rated 400 volts or less, you're in for a substantial saving in weight, size and cost by specifying General Electric's new 400-volt Pyranol units. Compared with 600-volt ratings, these new, standard, 400-volt capacitors will save you from 24 to 51 per cent in volume, 23 to 33 per cent in weight, and approximately 10 per cent in cost. They are available in 2-, 4-, 6-, 8- and 10-muf ratings with solder-lug or screw-thread terminals optional on the four larger sizes; the 2-muf size comes with solder-lug terminals only.

New developments, such as silicones and new paper, are continually improving the quality of G-E capacitors. They also permit our engineers to handle your new requirements to your complete satisfaction. Write for quotation on any capacitor needs, or check Bulletin GEA-2621 for more information on the new d-c line described above.

NEW, SMALLER SELENIUM RECTIFIER



This new General Electric selenium rectifier, less than one inch long and one inch square, is available now for receiver and other elec-

GENERAL ELECTRIC

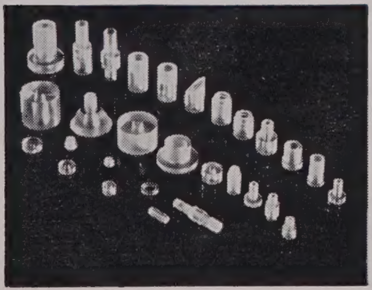
Digest

TIMELY HIGHLIGHTS ON G-E COMPONENTS

tronic applications. It costs little and mounts in places where a rectifier tube and socket won't fit. Tests prove that this new selenium rectifier will outlast several 117-volt rectifier tubes. Installation is easier too—only two soldering operations and a minimum of mounting hardware are required.

These rectifiers have an exceptionally high inverse-peak rating, and the inverse current is extremely low even with peak voltages up to 350 volts. At rated current output, the forward drop is five volts or less. Ratings are based on ambients of 50 to 60 C. Check Bulletin 21-127 for more information on this and other General Electric radio rectifiers.

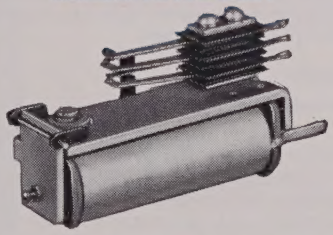
NEW MACHINABLE PLASTIC FOR UHF INSULATION



A new arrival in the plastics insulator field is G-E No. 1422, which offers characteristics of advantage in the manufacture of ultra-high-frequency equipment, television, FM, radar, and radio sets, and many other electronic applications. Possessing a dielectric constant of 2.5 to 2.6 with a power factor of .0006 to .0009 at 3000 mc, G-E No. 1422 exhibits unusual heat resistance and excellent machinability.

Indicative of its machinability is the industrial production of r-f connector beads from G-E No. 1422 on automatic and semi-automatic screw machines. As a low-loss dielectric in the hands of the electric-equipment designer, it affords an excellent low-cost means of producing experimental models and small production quantities through the use of standard machine shop tools. Check coupon for technical report.

HANDLES 12 CIRCUITS SIMULTANEOUSLY



This new telephone-type relay is capable of handling as many as 12 circuits in a wide variety of contact combinations. Designed for multipurpose use in industrial electronic apparatus, communications and signaling equipment, these devices have service lives measured in millions of operations. Working from five basic contact arrangements, combinations can be stacked to satisfy intricate circuit switching requirements. Silver, palladium, or tungsten contacts can be supplied; the choice depends on rating and life specifications.

More than 500 different coils are available, with ratings ranging from 1 to 250 volts, and 0.1 to 26,000 ohms. This varied selection of coil ratings makes it possible to match closely the coil voltage and resistance with the rating of the energizing circuits. Check Bulletin GEA-4859 for full details.

TO MEASURE TUBE LIFE

Now available for immediate delivery, General Electric Type KT time meters are ideal for inclusion in transmitters and other electronic equipment where knowledge of tube "on time" is important. They can record operating time in hours, tenths of hours, or minutes, and are built in four forms: round or square for panel mounting, portable with attached base, or for conduit mounting. Those designed for panel mounting are housed in small Textolite cases that harmonize with other panel devices.

Telechron motor drive assures an accurate record of tube operation over a long period of time. They can also be used on electronic production tools, such as resistance welders, to keep an accurate record of machine operating time. Researchers use them for measuring time intervals, verifying circuit operation, and life testing. Bulletins GEA-3299 and GEA-1574 have full details.

GENERAL ELECTRIC COMPANY, Section J642-16
Apparatus Department, Schenectady 5, N. Y.

Please send me:

☐ GEA-2621	400-v D-c Capacitors	☐ 21-127 Selenium Rectifier
☐ GEA-3299	Type KT Time Meter	☐ GEA-4859 Telephone-type Relay
☐ GEA-1574		☐ Report on G-E No. 1422 Plastic

NOTE: More data available in Sweets' File for Product Designers.

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MAGNETIC CONTROL of INDUSTRIAL MOTORS

By GERHART W. HEUMANN
Administrative Assistant, Control Engineering Division, General Electric Co.

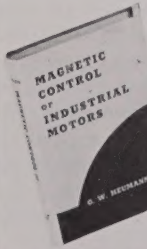
"His (Mr. Heumann's) apparent skill and broad knowledge of the subject make the acquirement of the book by those concerned with motor application and maintenance a thoroughly practical and rewarding investment.

"Mr. Heumann characterized the engineering of industrial control equipment as both a science and an art. His treatment of the science is excellent, and written to be understood by those who are familiar with the general principles of electrical engineering and electrical machinery.

"In order to cover the field he has defined, the author describes the characteristics of commonly encountered motor applications, and illustrates the circuit design, component selection and physical layouts by describing the controllers normally applied to the problem.

"The frequent use of photographs of the control equipment aids materially in giving the reader a grasp of the physical dimensions and external characteristics of the system under discussion. The inclusion of the material on amplidynes and their use in control systems is much to be commended since it is certain that these versatile and still relatively unfamiliar devices will find wider and wider application with the passing years..."

—*Richard Fleming,
Consulting
Engineer, N. Y.



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LIBRARY NOTES

ON ARTICLES IN OTHER TECHNICAL JOURNALS

AIR FLOW

Linearized Subsonic and Supersonic Flow About Inclined Slender Bodies of Revolution.

E. V. Laitone—*Jour. Aero. Sci.*, Nov., 1947; v. 14, pp. 631-642.

A mathematical article, with bibliography.

AIRPLANES

Analysis for Optimum Transport Airplane Configuration.

Philip A. Colman—*Aero. Engng. Rev.*, Dec., 1947; v. 6, pp. 20-27.

The turbine-jet engine is considered superior for the highest speed, short-range operation for any pay load; the turbine-propeller engine for all other conditions.

AMPLIFIERS, DYNAMOELECTRIC

Amplidyne Gives Quick Response on Synchronous Condenser Fields.

J. H. Vivian and F. V. Gillum—*Elec. Wld.*, Dec. 20, 1947; v. 128, pp. 68-71

Experiences of the Southern California Edison Co.

ARC WELDING

Motor Frames Welded by Submerged-Arc.

J. B. Arthur—*Am. Mach.*, Dec. 4, 1947; v. 91, pp. 106-109.

Using specially built machines and fixtures, motor frames are fabricated on a mass-production basis.

BRAKES

External Friction Blocks and Shoes.

A. C. Rasmussen—*Prod. Engng.*, Dec., 1947; v. 18, pp. 134-136.

Conditions that make external contracting shoes self-energizing and self-locking are described and recommendations made for positioning the hinge pin, choosing dimensions, and selecting linings to embody self-energization and self-locking into the design of brakes.

CAPACITORS

Paper Capacitors Containing Chlorinated Impregnants.

D. A. McLean—*Ind. & Engng. Chem.*, Nov., 1947; v. 39, 1457-1461.

Benefits of controlled oxidation of the paper.

DRYING

Vacuum Drying of Paper.

N. M. Foote—*Ind. & Engng. Chem.*, Dec., 1947; v. 39, pp. 1642-1646.

The removal of water, important in many technical processes, is shown to be of special importance in the manufacture of radio parts employing electric insulating paper.

ELECTRIC CONTROL SYSTEMS

Electronic Motor Drives Increase Machine Tool Versatility.

R. B. Crawford—*Mach.*, Dec., 1947; v. 54, pp. 156-159.

ELECTRIC MACHINERY

Generator Ratings and Load-carrying Capabilities of Generating Plants and Systems.

J. H. Foote—*Edison Elec. Inst. Bul.*, Nov., 1947; v. 15, pp. 339-401.

The compatibility of the kw ratings and actual load-carrying capabilities of the prime mover, its associated electric generator, and the system load which it will satisfy.

ELECTRIC MOTORS, FRACTIONAL-HP

Hysteresis Synchronous Motors Embody New Desig Principles.

Herbert C. Roters—*Elec. Mfg.*, Dec., 1947 v. 40, pp. 102-106, 198, etc.

By bridging over stator slots, distributing the winding, and using polyphase revolving field, parasitic losses are minimized and a new line of motors with good efficiencies is made possible.

ELECTRIC TRANSMISSION LINES

Economics of High-voltage Transmission by Under ground Cables.

R. N. Berry—*I. E. E. Jour., Pt. II*, Dec. 1947; v. 94, pp. 573-590.

A study of costs, choice of cable types and sizes, losses, etc.

ELECTROCHEMISTRY

New Mercury Cell Makes Its Bow.

W. C. Gardiner—*Chem. Engng.*, Nov., 1947 v. 54, pp. 108-112.

Illustrated description of the first commercial application of the mercury cell for electrochemical processes.

ENGINEERING

Machines-Tailored-To-Man Kindle New Engineering Design Concepts.

Leonard C. Mead—*Soc. Auto. Engrs. Jour.* Dec., 1947; v. 55, pp. 40-46.

Points out that the design of engineering structures is always subject to the physica limitations of the man who must operate the device. This is conspicuously obvious in the design of aircraft.

FILING

Personal Data File Saves Valuable Time.

George O. Guesmer—*Civil Engng.*, Dec. 1947; v. 17, p. 753.

Explains the author's simplified method o classifying and filing clippings, pamphlets photographs, etc., in the maintenance of a personal file of engineering data. Include subject-heading list used to cover the field o civil engineering.

FILMS

Concave Metallic Replica Gratings.

I. Simon—*Rev. of Sci. Instr.*, Dec., 1947; v 18, pp. 894-896.

Describes a method of producing metallic replicas from gratings by electrodeposition of copper. It is possible to obtain concave replicas from a convex original grating—either metallic or glass.

FOUNDRY PRACTICE

Aluminum Alloy Castings.

Floyd A. Lewis—*Foundry*, Dec., 1947; v 75, pp. 74-77, 186-188, 190.

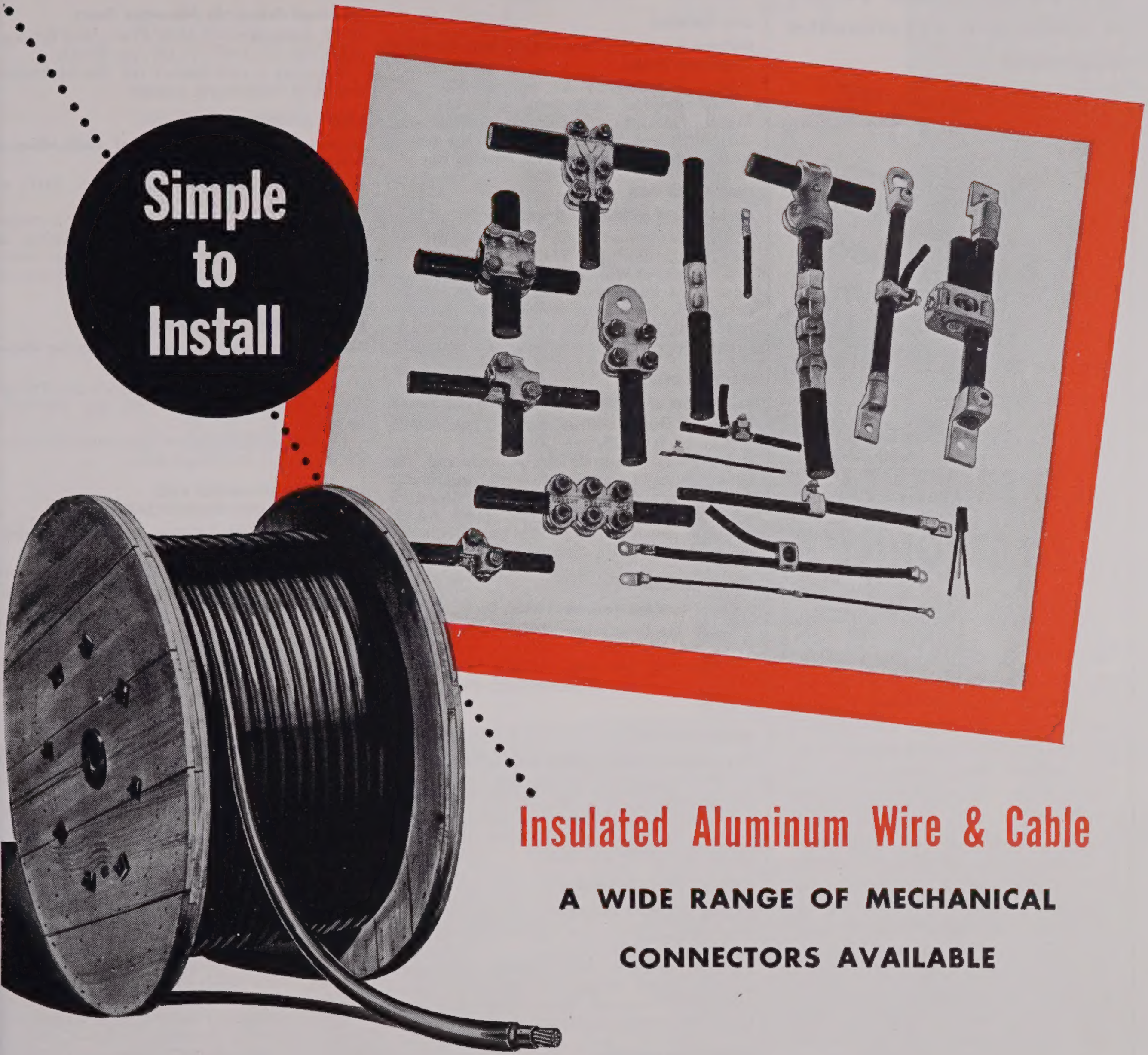
The first article of a series on aluminum alloy foundry practice.

Electromagnetic Pumping of Molten Metals.

Mario Tama—*Iron Age*, Dec. 4, 1947; v 160, pp. 68-70.

The electromagnetic method of pumping in conjunction with the induction melting furnace, appears to offer new and improved techniques for permanent mold and diecasting operations. Flow is controlled by variations of induced current.

(Continued on page 64



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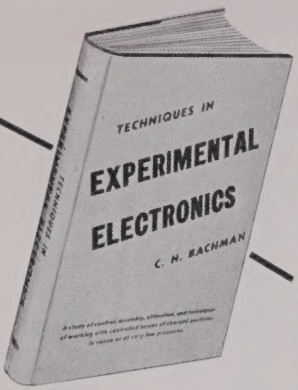
APR 1 5

What procedures must you use to make A-1 experimental equipment?



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LIBRARY NOTES (continued)

GAS TURBINES

1000-kw Gas-turbine Plant Features New Centrifugal Compressor Design.

Power, Dec. 1947; v. 91, pp. 851-853.

Experimental open-cycle unit built by Maschinenfabrik Oerlikon, Switzerland, completes test run. It uses a low-pressure system for injecting fuel for combustion.

INSULATING OILS

Advantages of an Inhibited Transformer Oil.

T. E. Reamer and R. G. Larsen—*A.S.T.M. Bul.*, Dec., 1947; pp. 58-65.

The factors which lead to the deterioration of transformer oils in service are described. Numerous accelerated tests for measuring the stability of such oils are considered together with criteria of evaluation.

MACHINE DESIGN

Acceleration of Inertia Loads with a Varying Torque.

James D. Burby—*Prod. Engng.*, Dec., 1947; v. 18, pp. 102-105.

Describes methods for calculating the time required to accelerate a rotating inertia load by a torque that can be defined or approximated as a function of speed. An example of use of the method is the calculation of motor drives for flywheels.

METAL CLEANING

Abrasive Tumbling Reduces Finishing Cost.

Vallory H. Laughner—*Mach.*, Dec., 1947; v. 54, pp. 139-146.

Deburring, cleaning, and finishing operations, both in job shops and high-production plants.

METAL CUTTING

Oxyacetylene Powder Cutting and Scarfing.

D. H. Fleming, Jr.—*Steel*, Dec. 1, 1947; v. 121, pp. 96-97, 120, 123, 126.

How the powder cutting reaction overcomes difficulties encountered in cutting oxidation-resistant metals.

METALS—PRESS-WORKING

Forming Thin-metal Cylinders.

Wallace C. Mills—*Am. Mach.*, Dec. 4, 1947; v. 91, pp. 96-103.

Small cylinders with open or lock seams demand good tooling for economical and efficient production. Given here are a number of extremely successful designs.

METALS, PULVERIZED

Sieve Test of Metal Powders.

Rolla E. Pollard—*Nat. Bur. Stds. Jour. Res.*, Dec., 1947; v. 39, pp. 487-505 (RP No. 1843.)

How reproducible results were obtained in sieve tests of sponge iron, electrolytic iron, electrolytic copper, and nickel when certain variables affecting the sieving characteristics of the powders were eliminated or controlled.

PHOTOTUBES

Infrared Image-converter Tube.

T. H. Pratt—*Jour. Sci. Instr.*, Dec., 1947; v. 24, pp. 312-314.

A form of photocell in which the anode is replaced by a fluorescent screen. For various applications where infrared radiation can be used to provide certain indications of value in industry as well as in war.

PLASTICS

Quantitative Tests on Finished Mouldings.

William D. Owen—*I. E. E. Jour., Pt. II*, Dec., 1947; v. 94, pp. 635-649.

British standard test methods for determining various properties of plastics used in the electrical industry.

PUMPS

Centrifugal Pumps—An Alternative Theory.

H. H. Anderson—*I.M.E. Proc.*, War Emerg. Issue No. 27, 1947; v. 157, pp. 57-84.

Suggests a new theory for the hydraulic design of centrifugal pumps.

RADIO ENGINEERING

Measurement and Suppression of Radio-influence Voltage.

R. S. Davidson—*Elec. Mfg.*, Dec., 1947; v. 40, pp. 79-81, 174, etc.

Why, from several methods, use of a radio-noise and field-strength meter within a screened enclosure was chosen as best. Measurements on d-c machines and means of suppression are described.

REFRIGERATING ENGINEERING

Desirable Desiccant Properties for Refrigerant Water Removal.

P. L. Veltman and C. E. Waring—*Refrig. Engng.*, Dec., 1947; v. 54, pp. 550-553, 584-585.

On the performance of desiccants for combating water in refrigerants.

SPECTROPHOTOMETERS AND SPECTROPHOTOMETRY

Recording and Control System for Infrared Spectrophotometer.

Gerald M. Rassweiler and others—*Optical Soc. of Am. Jour.*, Dec., 1947; v. 37, pp. 963-974.

STEEL, ALLOY

An Evaluation of Boron-treated Steels.

Walter F. Toerge—*Steel*, Dec. 8, 1947; v. 121, pp. 93-98, 100, 102, 104.

Data on the properties of steels so treated.

STRAINS AND STRESSES

X-ray Method of Measuring Poisson's Ratio.

R. F. Hanstock and E. H. Lloyd—*I.M.E. Proc.*, War Emerg. Issue No. 26, 1947; v. 157, pp. 52-55.

The measurement in metals by an x-ray diffraction method.

VIBRATIONS

Simplified Method for the Design of Vibration-isolating Suspensions.

R. C. Lewis and Karl Unholtz—*A.S.M.E. Trans.*, Nov., 1947; v. 69, pp. 813-820.

Presents a new type of chart-treating of coupled natural frequencies of suspended bodies showing frequency ratios, nodal positions, and optimum selection of ratios directly in terms of physical dimensions of body to be mounted.

VIBRATORS

Use of Vibration as a Means of Industrial Drive.

C. A. M. Thornton—*I.M.E. Proc.*, War Emerg. Issue No. 25, 1947; v. 157, pp. 20-31.

The construction and theory of vibratory machinery for screening, consolidating, facilitating flow of materials, and the like. Considers various kinds of systems and their drives.

VISION

Eyes on the Job.

Ethel M. Spears—*Conf. Bd. Man. Rec.*, Nov., 1947; v. 9, pp. 331-333.

How the Western Electric Co. uses the Bausch & Lomb "Ortho-Rater" for measuring the visual skills of employees.

WELDING

Advanced Techniques for Pressure Vessels.

Gerald Eldridge Stedman—*Weld. Engr.*, Dec., 1947; v. 32, pp. 36-40.

New methods in welding developed to speed and improve the production of specialized pressure vessels for many different industries.